SYSTEMS ENGINEERING
Research Center

Research on Building Education & Workforce Capacity in Systems Engineering

Interim Technical Report SERC-TR-016

Principal Investigator: Elisabeth McGrath, Senior Research Associate & Executive Director Center for Innovation in Engineering & Science Education (CIESE) (Stevens Institute of Technology)

Team Members: Christian Jurado, Research Associate (Stevens Institute of Technology

Dr. Susan Lowes, Director, Research and Evaluation, Institute for Learning Technologies, (Teachers College/Columbia University)
Sophie Lam, Research Assistant, Institute for Learning Technologies

Contract Number: H98230-08-D-0171, DO2, TTO2, RT#019
Report No. SERC-2011-TR-016
February 7, 2011

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **07 FEB 2011**	2. REPORT TYPE	3. DATES COVERED **00-00-2011 to 00-00-2011**

4. TITLE AND SUBTITLE **Research on Building Education & Workforce Capacity in Systems Engineering**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Stevens Institute of Technology,Systems Engineering Research Center (SERC),1 Castle Point on Hudson,Hoboken,NJ,07030**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
SERC is sponsored by the Department of Defense.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**54**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Table of Contents

I Executive Summary

Research on Building Education & Workforce Capacity in Systems Engineering, (referred to as the SE Capstone Project), is conducting research to understand the methods through which systems engineering learning and career interest may be increased among undergraduate and graduate engineering students. This research is being conducted in the context of 14 “capstone” courses, in most cases as an integrative culminating, project-based course involving teams of students working together on the development of a product or prototype that addresses a real Department of Defense need. Implemented as pilot courses in eight civilian and six military universities, these 14 institutions are piloting methods, materials, and approaches to create new courses or enhance existing courses to embed, infuse, and augment systems engineering knowledge, as defined by the SPRDE-SE/PSE Competency Model, among undergraduate and graduate students. This report is a snapshot of progress and preliminary findings as reported in SE Capstone partners’ interim reports as of January 2011 which, in most cases, represents the midpoint of their course implementation.

Each university chose one or more problem areas based on existing faculty expertise and interest. Two civilian universities and one service academy chose to work in more than one of the DoD problem areas. More than half the projects (8) addressed DoD Problem Area 1, with Problem Area 4 as the next most commonly addressed topic, with the remaining two problem areas divided among the other institutions.

The key features that differentiated the organizational structure of the programs at the different Institutions of Higher Education (IHEs) were the following:

- Faculty: The collaboration of two or multiple faculty members on course design and implementation. At 11 institutions, faculty came from at least three separate engineering disciplines, literally embodying the multi-disciplinarity of a systems engineering team. SE faculty were the largest percentage of participating faculty.
- Courses: The integration of the SE component into existing courses or the creation of entirely new courses.
- Course sequencing: The implementation of a course sequence that included an introductory course followed by a capstone experience or a capstone experience only.
- Student population: The involvement of either undergraduates and graduate students as learners[*] or only one of these.

[*] Some institutions engaged graduate students as teaching or technical assistants, but here we are referring to graduate students who are participating in the course for credit.

- Mentors: The presence and level of active and meaningful involvement of DoD and industry mentors in a variety of student learning experiences.

There was a diverse array of methods, approaches and structures for the implementation of the courses. All but one institution integrated the RT-19 effort into existing SE courses. Thirteen of the 14 projects implemented the RT-19 pilot over two semesters. One institution offered a single-semester capstone project course, and one conducted a one-semester course in the fall and spring semesters. Student teams ranged from four to seven members. Nine of the institutions had only undergraduates as students, two had exclusively graduate students and three had both. Class sizes varied widely across institutions, ranging from a low of 3 or 4 students to 48. The average class size was 20.

The most prevalent engineering discipline (among students) across all institutions was Systems Engineering, followed by Mechanical Engineering, Electrical Engineering, Computer Science/Software Engineering, and Industrial Engineering. Overall, the student population was over three-quarters male, with a small female population and a small percentage of students selecting not to report their gender. Students' reported ethnicities included 64 percent white; 11 percent Asian; 7 percent African American; 5 percent Hispanic/Latino; and Hawaiian or other Pacific Islander at <1 percent and unreported,11 percent. Approximately 40 percent of the students who returned surveys reported no experience with Systems Engineering and another 20 percent reported that they did not know if they had any such experience—for a total of 60 percent of the total population. Of those students who did report previous systems engineering experience (multiple responses were allowed), 25 percent had taken coursework, 12.5 percent had had full-time employment in systems engineering, 7 percent had a coop or internship experience, and 1 percent had systems engineering work experience during the academic year.

Over half (52 percent) of all students reported a level of high interest in becoming a systems engineer, 18 percent reported moderate interest, and 1 percent reported little interest. Forty-two percent of the students reported that they might want to work for the government as a systems engineer.

Projects with DoD mentors reported very different levels of interaction. Over 46 percent of PIs reported that their DoD mentors were "very involved;" another 46 percent reported not having a mentor or not yet working with their mentor. DoD mentors facilitated student learning in a variety of ways; however, their roles differed instructionally depending on whether they also served as clients, as they did for 50 percent of participating institutions.

Industry mentors took on roles similar to the roles played by DoD mentors—as clients, consultants, or SMEs. PIs at two institutions that had both industry and DoD mentors reported that having both types of mentor benefited the students' projects.

It is premature at this stage of course implementation to correlate student outcomes with the structure or content of the courses or with any particular strategies or course materials. However, the PIs' interim reports provide some insights into preliminary lessons learned about course objectives and implementation. These observations fall into several categories:

1. Challenges teaching the broad topic of systems engineering to non-SE majors under time constraints.

2. Challenges with equivalent grading policies in multi-disciplinary teams, particularly where SE was an overlay to an existing multi-disciplinary team structure.

3. Challenges with content-domain-specific problem areas and with finding meaningful ways for other disciplinary majors to contribute.

4. Motivating external mentors to bring authentic professional experiences to the learning experience.

5. SE content modules provide opportunities to bring non-SE majors to a common understanding. These have been implemented with varying frequency, durations, and numbers across several projects.

6. Efforts to provide specific disciplinary expertise (internal and external) to infuse sufficient content knowledge into student teams such that students are able to focus on the bigger SE competencies.

It is also not clear at this stage the extent to which RT-19 funding has created entirely new materials or simply (and in some cases, substantially) enhanced existing courses. This is an area for further investigation.

Recommendations that emerge from a review of the implementing institutions' interim reports suggest that:

1. More planning time is needed to effectively plan and coordinate course materials and assessments; make optimal use of external resources such as DoD and industry mentors, as well as facilities visits; and to secure buy-in and define roles and responsibilities of interdisciplinary faculty participants.

2. In order to effectively recruit students, the specific DoD problem area should be defined and disseminated to students at least at the time students register for their next cycle of courses (the term prior to the course implementation).

3. Better connections, more clearly defined roles, and stronger commitment by DoD and industry mentors would enhance students' experiences in cases where the participation of external mentors has been lacking. Consideration of a nominal

financial commitment by external clients may increase the investment/commitment by these mentors.

4. A list of required and recommended faculty events and student programs should be made available to PIs to encourage maximum participation and allocation of sufficient financial resources.

This report contains a snapshot of the richness of the 14 SE Capstone courses that have been and are being implemented at 14 institutions. At this point in project implementation, it is not possible to provide an analysis of student learning outcomes. The final report will aim to connect the course content and organization, including materials created by faculty as well as the contributions of external mentors, with impacts on student learning of SE content, their interest in SE careers, and their interest in DoD problem areas and careers.

II Introduction

A 45% increase is expected in systems engineering (SE) jobs in the next decade[1] and there have been numerous studies and workshops that have highlighted the shortfalls in both the number and capability of the SE workforce. The July 2006 National Defense Industrial Association (NDIA) Task Force noted among the top five systems engineering issues the lack of adequate, qualified SE human capital resources within Government and industry for allocation on major programs.[2] A July 2010 NDIA white paper on critical systems engineering challenges identified Issue 2 as: *The quantity and quality of systems engineering expertise is insufficient to meet the demands of the government and defense industry*, and further outlined certain recommendations to build SE expertise and capacity. In particular, it recommended developing SE expertise through "role definition, selection, training, career incentives, and broadening 'systems thinking' into other disciplines," and made a number of specific recommendations:

> b. Continue to work with major universities and professional societies to add an introductory course in SE in all undergraduate engineering and technical management degree programs (task for NDIA SED Education and Training (E&T) Committee).
>
> c. Work with major universities and recommend SE curricula to improve consistency across university programs and help achieve standardization of skill sets for graduates. (Task for NDIA SED E&T Committee.)[3]

Consequently, new academic and career pathways are urgently needed to build the talent base required. Despite an increased focus on science and engineering education from elementary through higher education since the launching of the Sputnik,[4] with the number of undergraduate and graduate systems engineering degree programs offered in the United States reaching 165 programs across 80 institutions,[5] the best methods and approaches for developing systems engineering curriculum continue to evolve as the discipline evolves.[6,7,8,9]

RT-19, *Research on Building Education & Workforce Capacity in Systems Engineering* (referred to as the SE Capstone Project) is expected to provide a substantial addition to this knowledge base. This research is being conducted in the context of 14 "capstone" courses, in most cases as an integrative culminating, project-based course involving teams of students working together on the development of a product or prototype that addresses a real Department of Defense need. Implemented as pilot courses in eight civilian and six military institutions of higher education (IHEs) affiliated with the Systems Engineering Research Center (SERC), these 14 institutions are piloting methods, materials, and approaches to create new courses or enhance existing courses to embed, infuse, and augment systems engineering knowledge, as defined by the SPRDE-SE/PSE Competency Model, among undergraduate and graduate students. This pilot program is being conducted in order to inform the development of a national scale-up effort that would substantially expand the number and capabilities of universities able to produce systems engineering graduates. It is anticipated that the implementation of the pilot courses will lead to the identification of strategies for student recruitment, exemplary course materials, assessment instruments, models for external mentorship, and other lessons that may be deployed to accelerate the adoption of effective practices and materials in a national scale-up.

III Background

In the past decade, in an effort to address workforce development needs in systems engineering, separate competency models for systems engineering have been developed by individual companies, consortia, and professional societies. Descriptions and comparisons of these models are available from a variety of sources.[10,11,12] Over the last few years, one such model development took place in the defense acquisition community. Subject matter experts developed and validated the Systems Planning, Research Development, and Engineering (SPRDE) Systems Engineering (SE) and Program Systems Engineer (PSE) competency model, known as the SPRDE-SE/PSE. The SPRDE-SE/PSE competency model is comprised of twenty-nine areas of competency grouped according to three primary "units of competence" – analytical, technical management, and professional – as shown below.[13] The analytical unit covers thirteen competencies related to the technical base for cost and aspects of the system life cycle. The technical management unit addresses twelve competencies on the technical side of project management, and the professional unit covers the broader competencies of communication, problem solving, systems thinking and ethics.

In general, competency models are used not only for workforce selection and development, but also for educational purposes. In particular, systems engineering competency models are becoming more widely used in support of systems engineering workforce development, education, and training.[14,15,16,17,18] This research therefore draws upon the SPRDE-SE/PSE competency model to define learning objectives for a set of courses being implemented across the 14 piloting universities.

SPRDE-SE/PSE Competency Model

Analytical (13)	1. Technical Basis for Cost
	2. Modeling and Simulation
	3. Safety Assurance
	4. Stakeholder Requirements Definition (Requirements Development)
	5. Requirements Analysis (Logical Analysis)
	6. Architectural Design (Design Solution)
	7. Implementation
	8. Integration
	9. Verification
	10. Validation
	11. Transition
	12 System Assurance
	13. Reliability, Availability, and Maintainability
Technical	14. Decision Analysis

Management (12)	15. Technical Planning
	16. Technical Assessment
	17. Configuration Management
	18. Requirements Management
	19. Risk Management
	20. Technical Data Management
	21. Interface Management
	22. Software Engineering
	23. Acquisition
	24. Systems Engineering Leadership
	25. System of Systems
Professional (4)	26. Communications
	27. Problem Solving
	28. Strategic Thinking
	29. Professional Ethics

The 14 pilot universities are required to address one or more of four DoD problem areas and to produce an actual product, prototype, or other artifact to demonstrate their learning.

DoD Problem Areas

1. Low-cost, low-power computers leveraging open-source technologies and advanced security to support sustainable, secure collaboration;
   Portable, renewable power generation, storage, and distribution to support sustained operations in austere environments and reduce dependency on carbon-based energy sources;
   Portable, low-power water purification;
2. An expeditionary assistance kit around low-cost, efficient, and sustainable prototypes such as solar cookers, small and transportable shelters, deployable information and communication technologies, water purifiers, and renewable energies. These materials would be packaged in mission-specific HA/DR kits for partner nation use;
3. Develop modular, scalable, expeditionary housing systems that possess "green" electric power and water generation, waste and wastewater disposal, hygiene, and food service capabilities. Systems should be designed to blend in to natural/native surroundings and with minimal footprint;
4. Continued investigation and exploration into the realm of the possible with respect to "Immersive" training technologies. Objective is to flood the training audience environment with the same STIMULI that one would experience during actual mission execution. Where possible full sensory overload is desired much the same as experienced in combat. Specific S&T areas for development
   Virtual Human. Successful modeling of emotions, speech patterns, cultural behaviors, dialogue and gestures.
   Universal Language Model. The ability for trainees to seamlessly converse with the Virtual Human.
   Virtual Character Grab Controls. The ability for exercise controllers to assume control of virtual characters.
   Automated Programming. Cognitive learning models and the ability for exercise controllers to adjust virtual/live simulations.

The program is being implemented in three sequential phases over a 19-month period. During Phase 1/Planning and Startup (March 1, 2010-May 15, 2010), the research team, with participation from the sponsor agency:

- Developed the requirements and specifications, timeline, and funding limits for the SE Capstone Projects
- Developed the research design and project evaluation plan
- Developed the common assessments required of all projects and the model for projects
- Developed and issued the request for proposals and selection process (an independent review team and rubric) for selecting participating institutions
- Concluded with the selection of eight civilian universities and six service academies with SE programs that would participate in the SE Capstone pilot

Phase 2/Pilot Implementation (May 15, 2010-June 30, 2011) focuses on the development, implementation, and evaluation of the courses at 14 institutions. Implementation ranges from a one-semester "broad spectrum" introduction to systems engineering course to a two-semester senior design course, to a supplemental independent-study approach that augments a traditional senior design course with SE modules. During this phase, the institutions have recruited student teams; organized the course structure (materials and faculty participation); identified and initiated collaborations with DoD and industry mentors to serve in a variety of roles with student teams; developed and administered their own course assessments based on the learning objectives of their particular courses; and are delivering the courses, the majority of which will continue through the spring semester.

Phase 3/Analysis, Recommendations & Dissemination (July 1, 2011 – September 30, 2011) will analyze the results from all Capstone Team Members and integrate them into a single set of observations to the sponsor about the effectiveness of the pilot programs, analysis of pre-/post learning of SE content, skills, and career interest, and the degree to which learning outcomes were achieved. It will also create specific recommendations on how to scale-up the pilot program to be conducted across the U.S. A key vehicle to synthesize findings across the various projects is a workshop for all SE Capstone Team projects, the government sponsor, representatives of industry, relevant professional societies and accrediting organizations (including ABET), and other interested parties in July 2011. At that workshop, the results of the individual SE Capstone pilots will be presented.

As part of the pilot, each university team is required to develop its own customized pre- and post-assessments tailored to the specific learning objectives in the courses it is developing. Since these are all different, each university team is also required to administer three common assessments to all participating students. These will be used to gauge student learning of specific concepts and skills related to systems engineering and will allow comparisons across universities, as well as provide data for correlating different outcomes with differences in implementation.

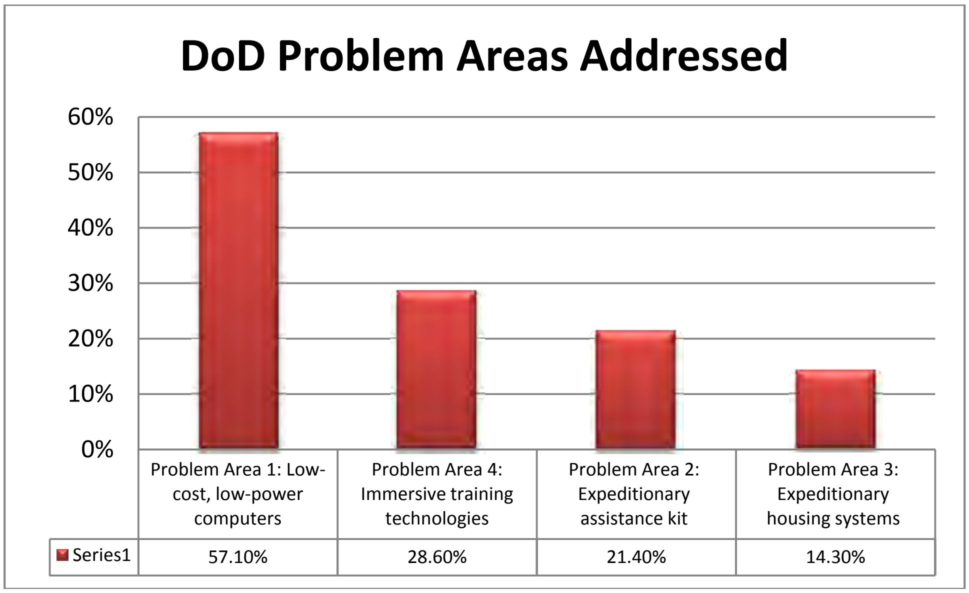
During the first months of the project, the research team met several times to lay out the specific objectives for student learning. The final objectives for students were that, at the end of the capstone course, participating students should:

- Understand what systems engineering is
- Understand what systems engineers do
- Understand the qualities and skills that systems engineers bring to projects
- Consider a career in systems engineering
- Develop and practice the skills of systems engineers
- Understand what systems engineers do/how systems engineers think (analytic skills)

This report will summarize progress as of January 2011. It is based on an analysis of each partner institution's interim report and the student baseline (pre-course) survey. A final section includes preliminary observations and recommendations.

IV DoD Problem Area Addressed

Each university chose one or more problem areas based on existing faculty expertise and interest. Two civilian universities and one service academy chose to work in more than one of the DoD problem areas. More than half the projects (8) addressed DoD Problem Area 1; Problem Area 4, with the remaining two areas divided among the other partner institutions:



The following table shows problem area(s) address by institution:

Auburn University	1
Missouri S&T University	4
Penn State University	2
Southern Methodist University	4
Stevens Institute of Technology	3
University of Maryland	1
University of Virginia	1,4
Wayne State University	1,3
Air Force Institute of Technology	1
Naval Postgraduate School	3
US Air Force Academy	1
US Naval Academy	1,2

US Military Academy	4
US Coast Guard Academy	1

V Structure and Organization of SE Capstone Courses

Each university organized the structure and content of its pilot course(s) differently, depending primarily on the existing structure of the capstone courses within the institution, the expertise and interests of the faculty recruited into the effort, the types of students, and the mentors available. The key features that differentiated the organizational structure of the programs at the different IHEs were the following:

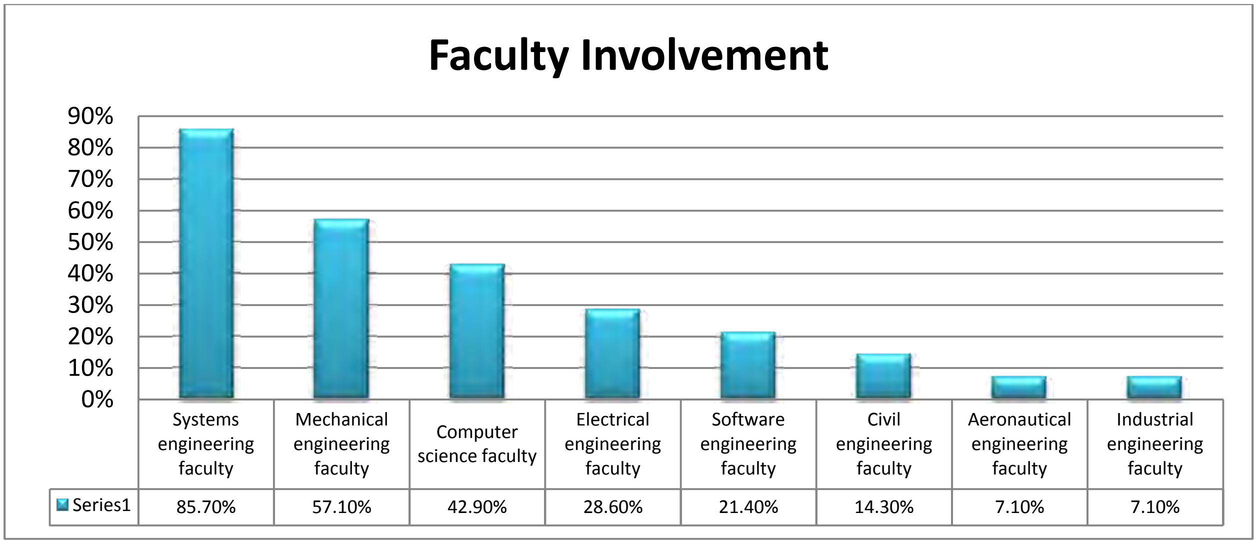
- Faculty: The collaboration of two or multiple faculty members on course design and implementation
- Courses: The integration of the SE component into existing courses or the creation of entirely new courses
- Course sequencing: The implementation of a course sequence that included an introductory course followed by a capstone experience or a capstone experience only
- Student population: The involvement of either undergraduates and graduate students as learners[†] or only one of these
- Mentors: The presence and level of active and meaningful involvement of DoD and industry mentors in a variety of student learning experiences

The following sections will discuss these in more detail.

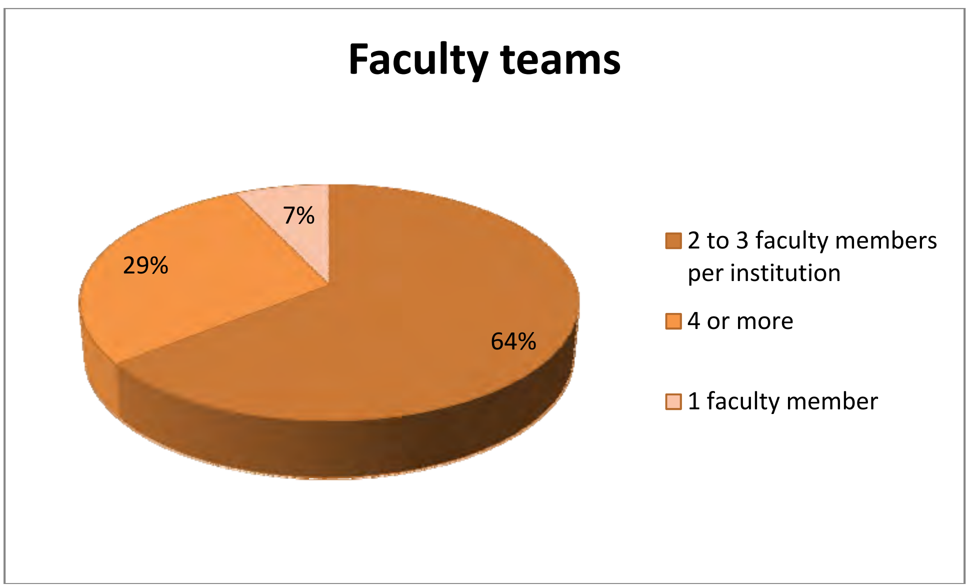
VI Faculty Involvement

A majority of the universities relied on the expertise of systems engineering faculty to lead or contribute to the conceptualization, development, and implementation of the program, but many other faculty were involved as well, particularly from mechanical engineering and computer science. At 11 institutions, faculty came from at least three separate engineering disciplines, literally embodying the multi-disciplinarity of a systems engineering team. In the following graph, percentages represent the percentage of the 14 pilot universities that included those types of disciplinary faculty in the RT-19 project:

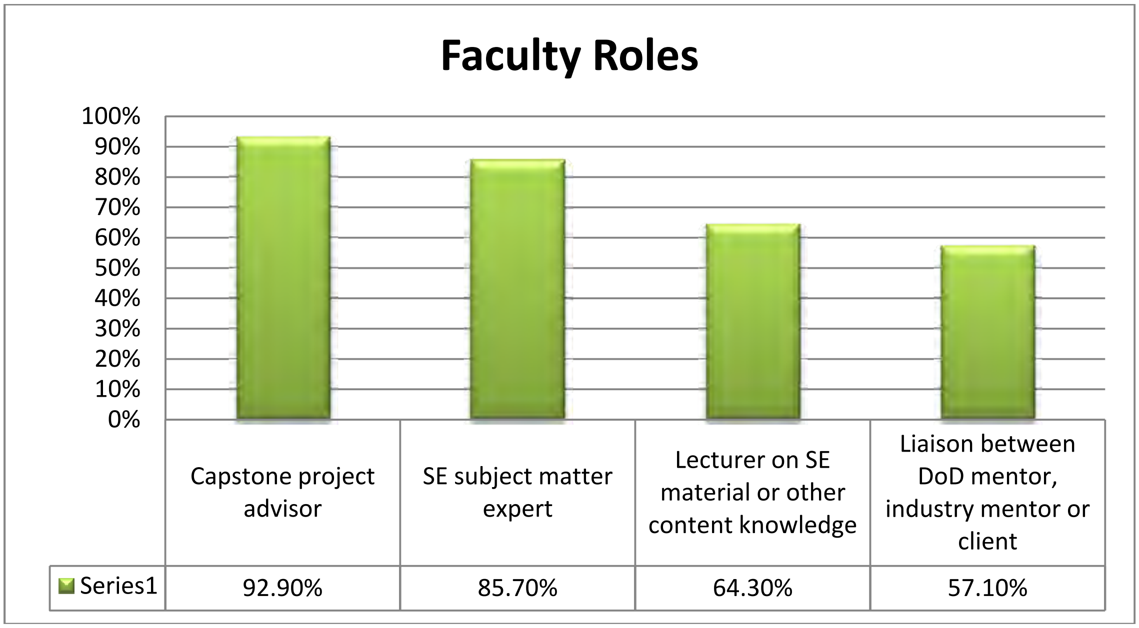
[†] Some institutions engaged graduate students as teaching or technical assistants, but here we are referring to graduate students who are participating in the course for credit.



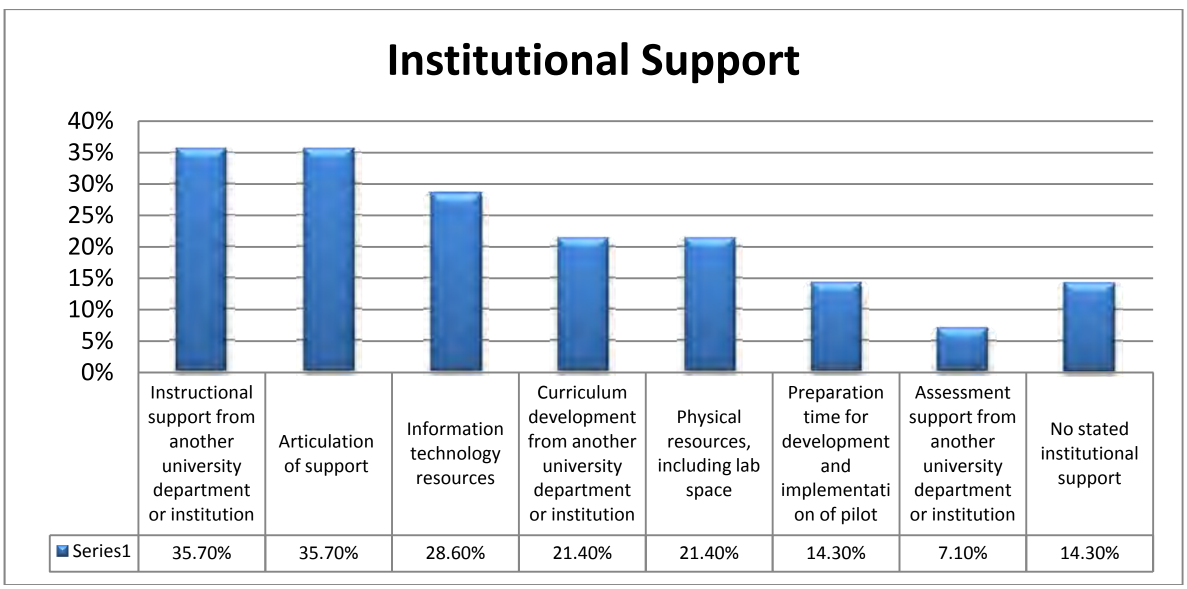
Nearly two-thirds of the fourteen projects were planned and implemented by teams of two or three faculty members, but four projects included four or more faculty. Only one institution developed a capstone course that was planned and taught by a single faculty member:



Faculty took on different roles, including that of classroom instructor, curriculum developer, project advisor, and SE subject matter expert, with some being several of these. In this graph, percentages represent the percent of all faculty in the project where faculty could play more than one role.



All PIs reported that their universities had been very supportive of the effort, with this support coming in a variety of forms:



VII Course Sequences, Structures, and Types of Student

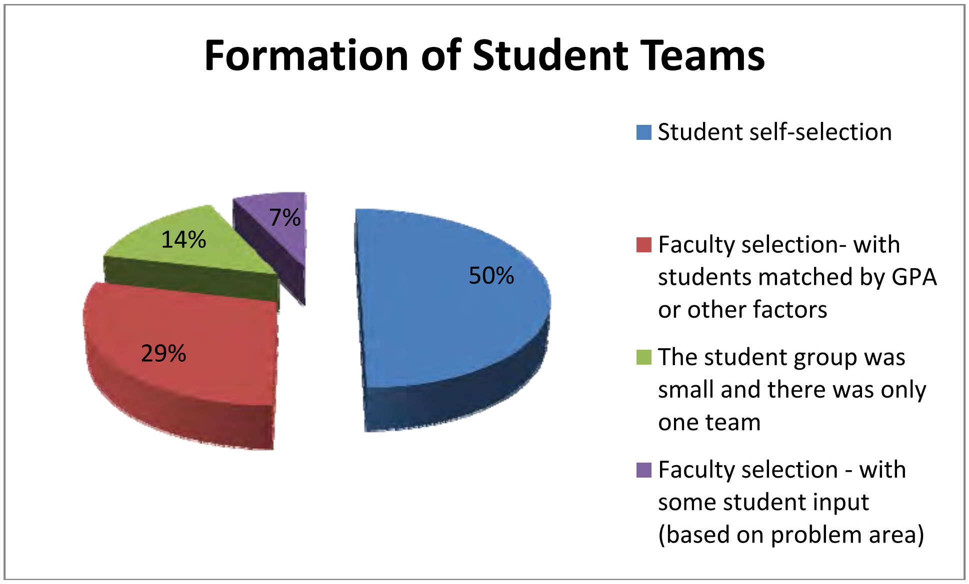
There was a diverse array of methods, approaches and structures for the implementation of the courses. The table on the following page summarizes the differences in type of student (graduate/undergraduate/both), course integration, and type of course sequence. (More detailed information for each institution can be found in Appendix 1.)

	Students: Undergraduates/ Graduate	Integrated into Existing SE Courses	Intro course + Capstone/ Capstone only
Auburn University	U	N	I/C
Missouri S&T University	U/G	Y	C
Penn State University	U	Y	C
Southern Methodist University	U	Y	I/C
Stevens Institute of Technology	U/G	Y	C
University of Maryland	U	Y	C
University of Virginia	U	Y	C
Wayne State University	U/G	Y	C
Air Force Institute of Technology	G	Y	I/C
Naval Postgraduate School	G	Y	I/C
US Air Force Academy	U	Y	C
US Naval Academy	U	Y	C
US Military Academy	U	Y	C
US Coast Guard Academy	U	Y	C

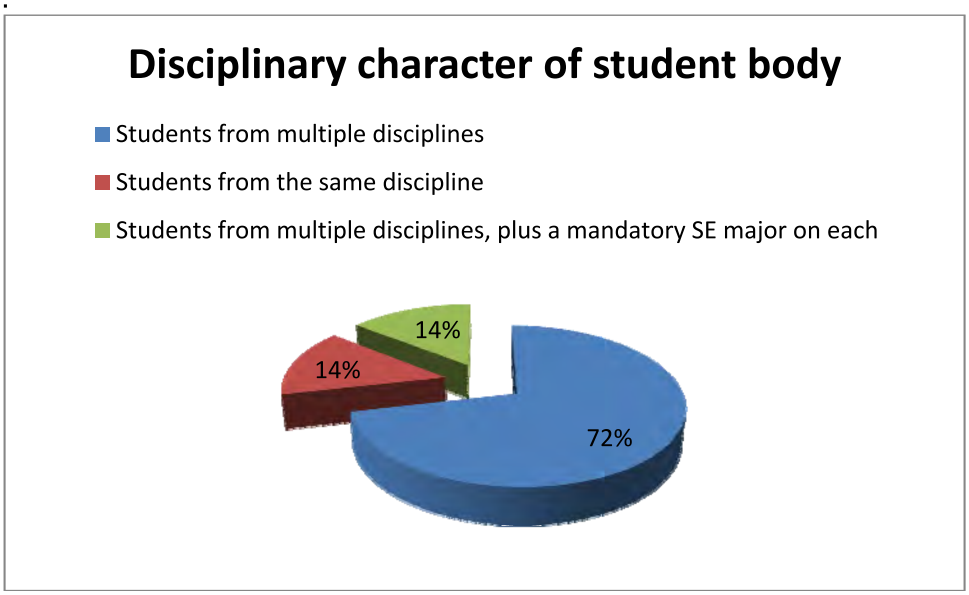
All but one institution integrated the RT-19 effort into existing SE courses, with only Auburn developing a completely new course. Thirteen of the 14 projects were structured into two semesters, with only one institution (Penn State) conducting a single-semester capstone project course. However, one (University of Maryland) is conducting two one-semester capstone courses (i.e., with different students). Those who carried over two semesters did so in one of two ways: (1) The first semester was an introduction to fundamental SE concepts and processes and the second was devoted to the development of the capstone design project or (2) both semesters were devoted to the capstone project work. Appendix 2 lists the course materials, course management systems, and software applications developed or used by each institution.

The student population also varied in terms of the mix of graduate students and undergraduates. Nine of the institutions had only undergraduates as students, two had exclusively graduate students and three had a mix. In addition, two institutions had graduate students acting as TAs or providing technical help. (See Section IX below for more on the student population.)

Student teams ranged from four to seven members. Teams met during class, at lab sessions at some institutions, and also communicated through a number of non-face-to-face channels, including e-mail, telephone, videoconference, weblogs, and on collaborative document sharing platforms. Teams generally submitted weekly progress reports and prepared final project presentations. At two institutions, student teams included distance students who communicated with their teams via their university Blackboard portal or the Stevens project-wide Sakai site. In half the universities, students chose their own teams; in the rest, faculty did so:



Over 75 percent of all capstone student teams were mixed in discipline, allowing faculty and students to experience working in a context resembling that of professional systems engineers:



VIII Student Recruitment

The nature of the funding cycle resulted in a very compressed period in which to recruit students for the SE Capstone project.The timeline varied across the different IHEs, according to the schedule of the start of classes, which ranged from as early as mid-August in some institutions to early September in others. Moreover, a majority of students selected the next year's courses in the prior term and have either no availability or flexibility in their schedules to make changes if a new course is announced late.

Those universities that already had existing capstone design courses in place were able to infuse DoD projects into them and were able to recruit students who had not yet committed to a specific project. For recruiting, most institutions relied primarily on face-to-face interactions with potential students and recommendations from other faculty members, and most relied on more than one avenue:

	Face-to-face recruiting	The course was required	Contacting senior design advisors or faculty from other departments	Flyers around university	Department website	Department e-mail listserv	Flyers around department	Institution website	Open house
Series1	64.30%	42.90%	35.70%	28.60%	21.40%	21.40%	21.40%	7.10%	7.10%

One PI noted that the presence of two DoD mentors at the initial recruitment session "was a key factor in the recruitment of the students … as it allowed students to ask questions and get a real feel for the purpose of the projects." Other reasons for successful student recruitment included "the humanitarian nature of the projects" or recommendations by student advisors.

On a scale of 1 to 5, the short time frame and resulting course scheduling issues were seen by the PIs as the most challenging factors in recruiting students, while administrative support and student interest were the least challenging factors:

	Least challenging (1)	(2)	(3)	(4)	Most challenging (5)	Average
Short time frame	1	0	1	3	6	4.18
Course scheduling issues	4	0	0	3	5	3.42
Lack of student interest	2	0	3	1	1	2.86
Lack of faculty support	6	1	3	0	0	1.70
Lack of administrative support	6	1	1	0	0	1.38

IX Analysis of Student Participants

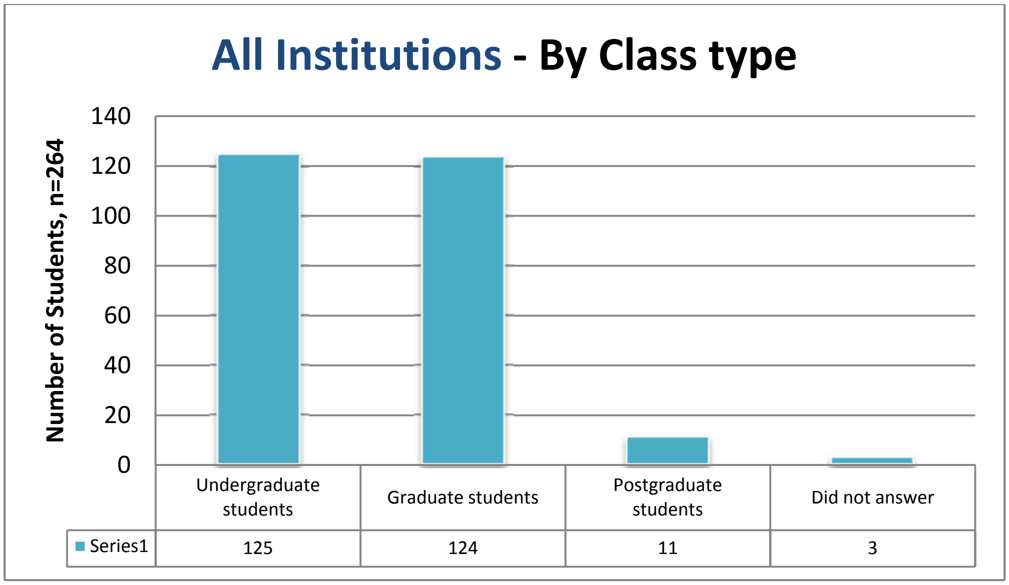
This section will provide an overview of the demographic characteristics of the students engaged in the RT-19 capstone courses, based on analysis of the student pre-surveys from 13 of the institutions that submitted them.[‡] Although there were differences among the institutions, this analysis will focus on the entire population.

Undergraduates/Graduate students

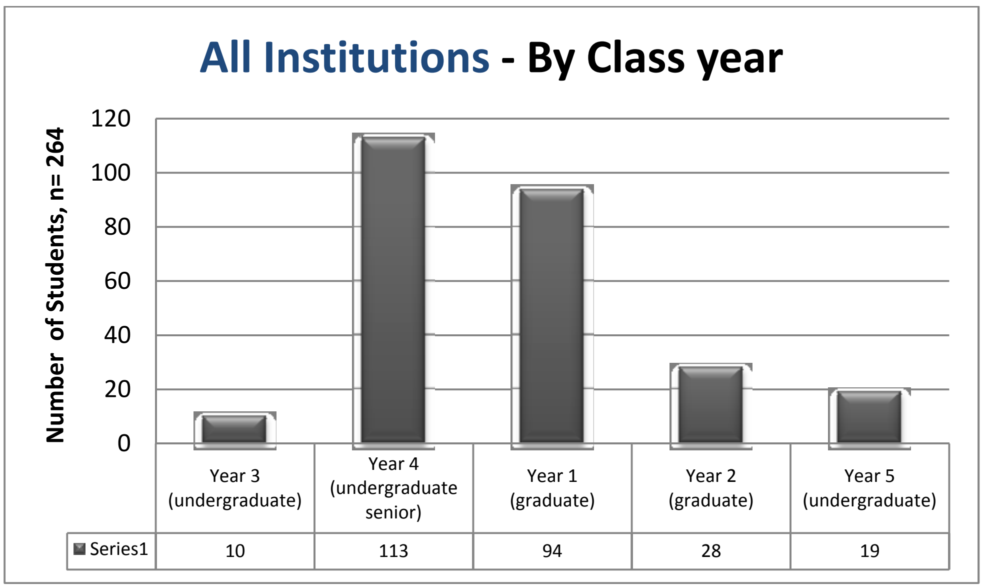
The total number of students returning surveys was 294. Of those, 127 were undergraduates, 124 were graduate students, and 11 were postgraduates.

While the total number of undergraduates and graduate students was nearly equal across the 13 institutions, a closer look at differences between individual institutions shows that nearly half of the 13 institutions (Penn State, UVA, SMU, CGA, AFA, and West Point) were comprised entirely of undergraduates. Four institutions (Wayne State, AFIT, NPS, and the Naval Academy) had graduate students (including postgraduate students) and the remaining three (Auburn, Missouri S&T, and Stevens) had mixed undergraduate and graduate populations. However, the ratio varied: while Auburn had mostly graduate and postgraduate students (92 percent), with fairly few undergraduates, Stevens had a 2:3 ratio of undergraduates to graduate students and Missouri S&T had a 1:4 ratio.

[‡] Baseline data is missing from the University of Maryland.



Most of the undergraduates were in their senior year and most of the graduate students were in their first year:

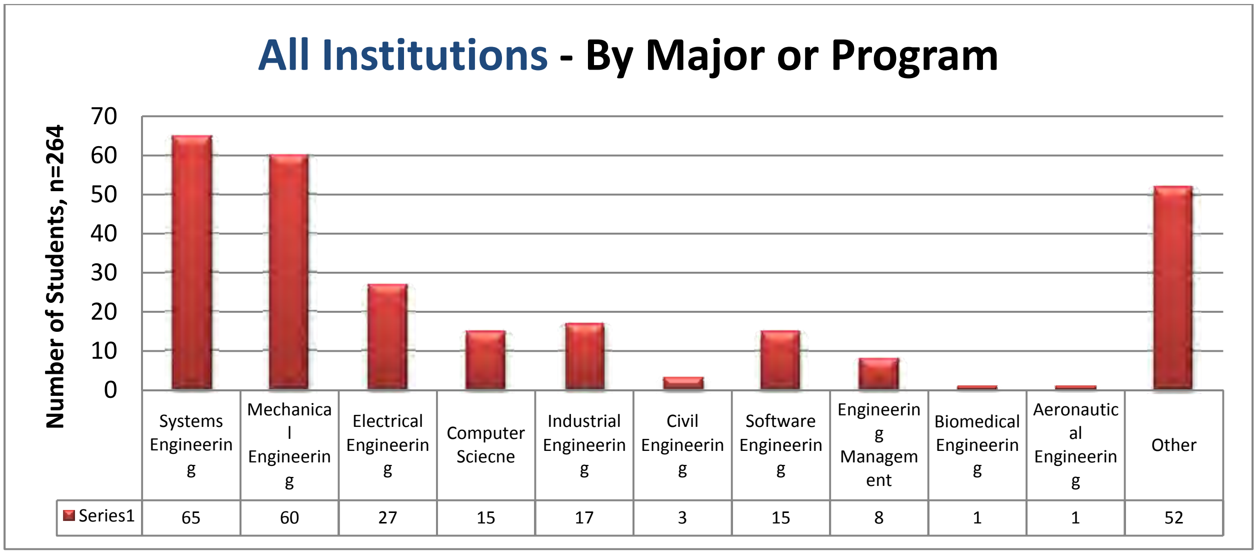


<u>Class size</u>

Class sizes varied widely across institutions, ranging from a low of 3 or 4 students (AFIT, USMA) to 48 (NPS). The average class size was 20 (median = 17, SD = 14).

<u>Major</u>

The most prevalent engineering discipline among students across all institutions was Systems Engineering, followed by Mechanical Engineering, Electrical Engineering, Computer Science/Software Engineering, and Industrial Engineering.

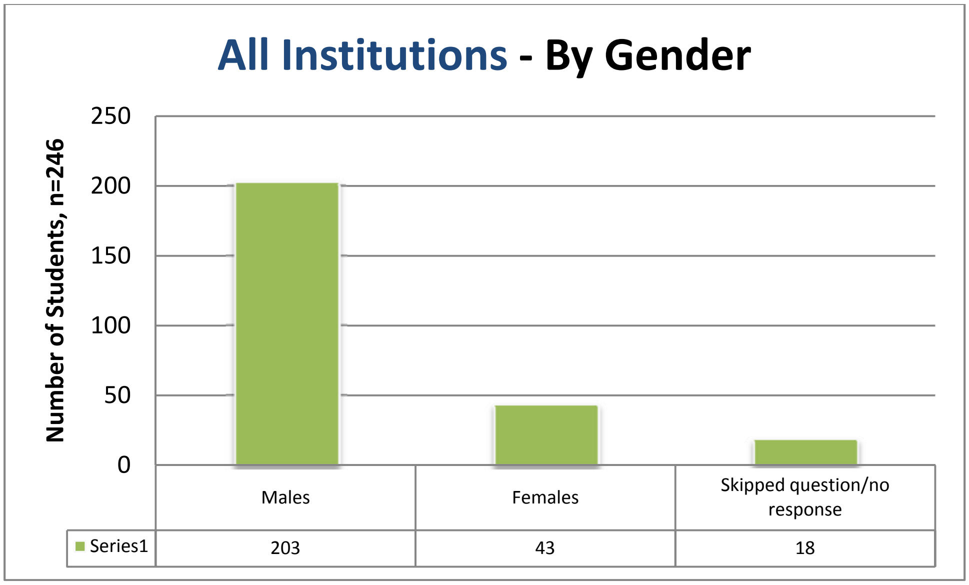


Twelve of the 13 institutions included students from two or more engineering disciplines. In one institution, Auburn, students came from as many as five different engineering disciplines. Only one institution (CGA) had all of its students from one discipline, mechanical engineering.

The most prevalent major among students overall was Systems Engineering, followed by Mechanical and Electrical Engineering. While about a quarter of the total (n=264) population returning surveys majored in Systems Engineering, these students were distributed among 8 of the 13 institutions. Students who majored in Mechanical Engineering, the second most popular engineering discipline, were distributed across 9 institutions. Electrical Engineering, the third most popular major, was distributed over six institutions. All Software Engineering and 87 percent of Computer Science major were in one institution, Auburn.

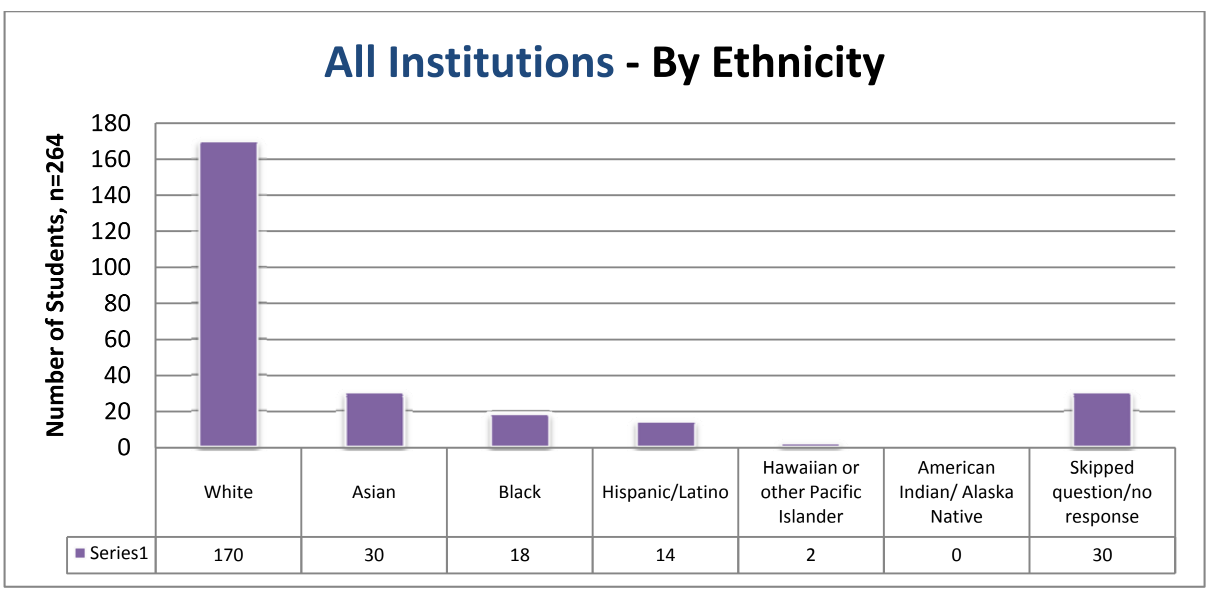
Other majors represented in student survey responses included Product Architecture; Alternative Energy Technology, Chemical Engineering, and Biomedical Engineering. However, the percentage of students majoring in these subjects across institutions was insignificant and they were often based in specific institutions.

Gender and Ethnicity



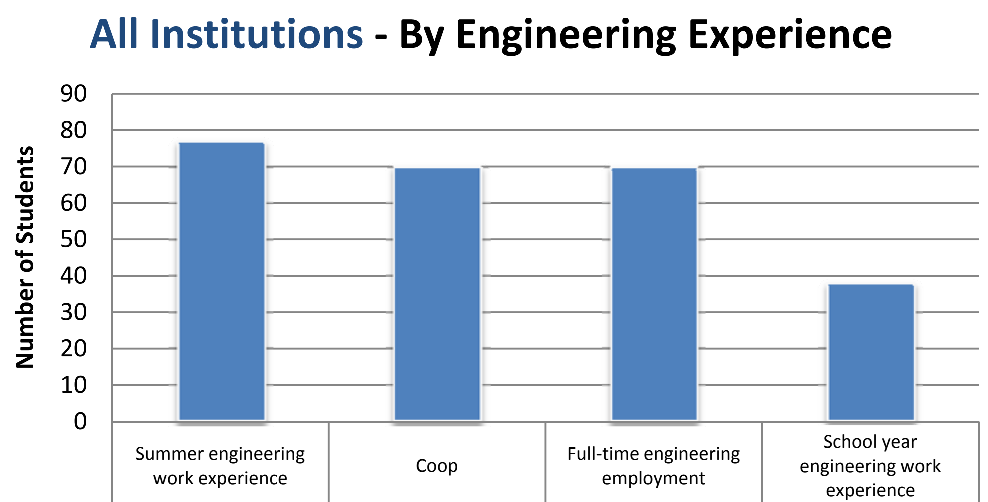
Overall, the student population (n=264) was over three-quarters male (77 percent), with a small female population (16 percent) and a small percentage of students selecting not to report their gender (7 percent).

Students' reported ethnicities (n=264) broke down into White (64 percent); Asian (11 percent); Black or African-American (7 percent); Hispanic/Latino (5 percent); Hawaiian or Other Pacific Islander (>1 percent); and unreported (11 percent).



Experience with Engineering

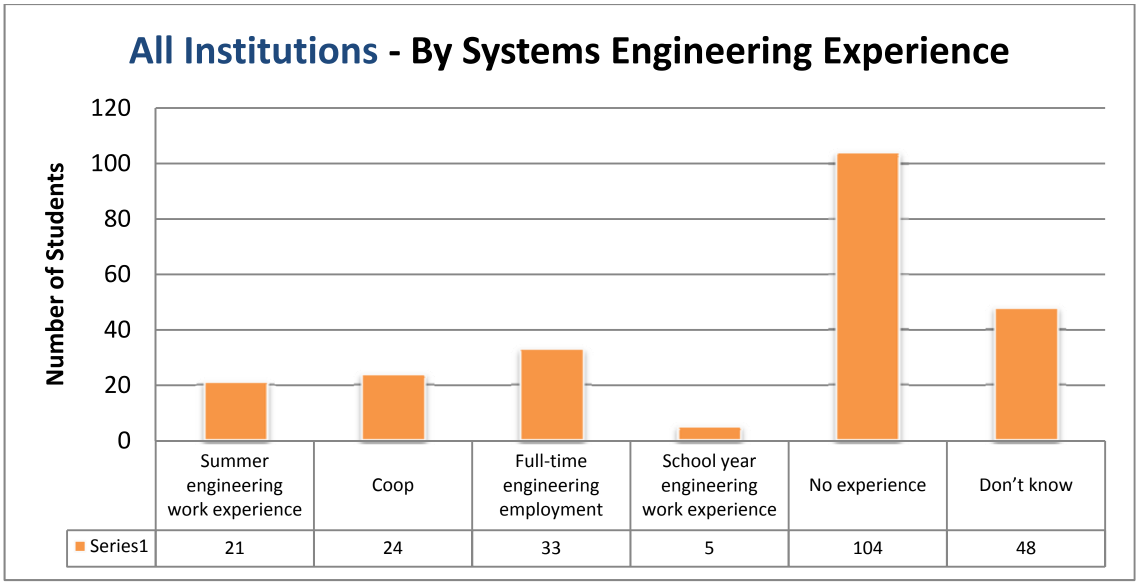
Students from 12 of the 13 institutions reported having engineering internship or cooperative experience. However, this varied greatly by institution, from a low of 12 percent of the students at one university to a high of 69.2 percent at another. Overall, students had the most engineering work experience during the summer, followed by full-time engineering employment, coop work, and work during the academic year. Students in over half of the institutions had engineering experience in three or more of these activities.



	Summer engineering work experience	Coop	Full-time engineering employment	School year engineering work experience
Series1	77	70	70	38

Experience with Systems Engineering

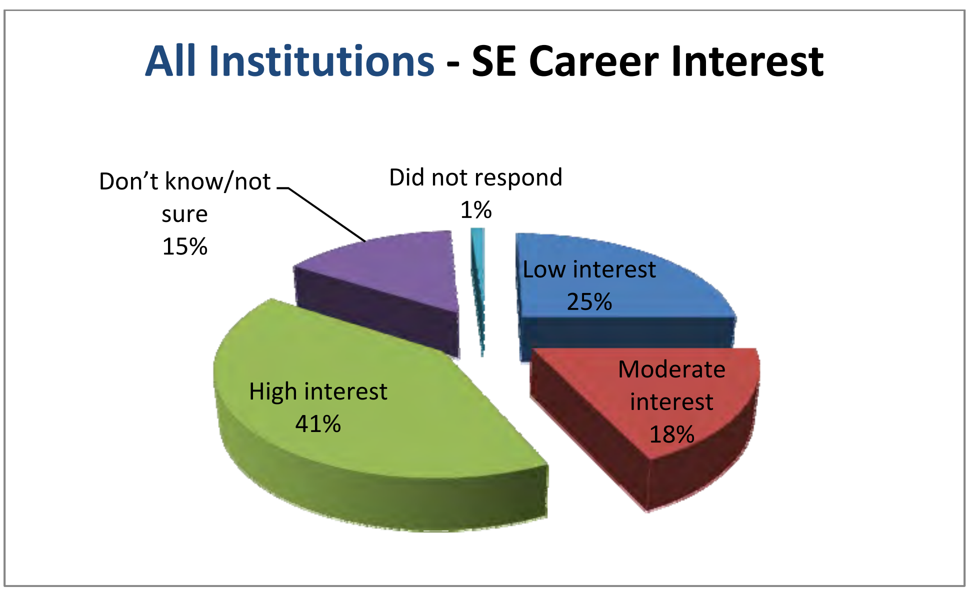
Despite over half of the student population having some form of engineering experience and the fact that there were Systems Engineering majors in many institutions, approximately 40 percent of the students who returned surveys reported no experience with Systems Engineering and another 20 percent reported that they did not know if they had any such experience—for a total of 60 percent of the total population. These students were distributed across 11 of the 13 institutions.



Of those students who did report having systems engineering experience (and the survey allowed them to check off multiple forms of work experience), 25 percent had taken coursework, 12.5 percent had had full-time employment in systems engineering, 7 percent had a coop or internship experience; and 1 percent had systems engineering work experience during the institution year.

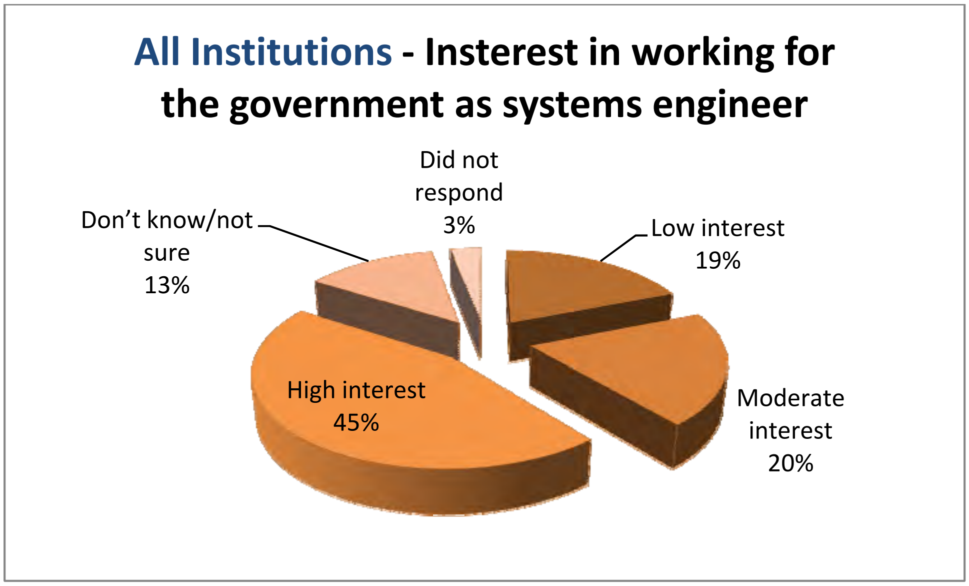
Interest in Systems Engineering as a Career

Over half (52 percent) of all students reported a level of high interest in becoming a systems engineer, 18 percent report moderate interest, and 1 percent reported little interest.



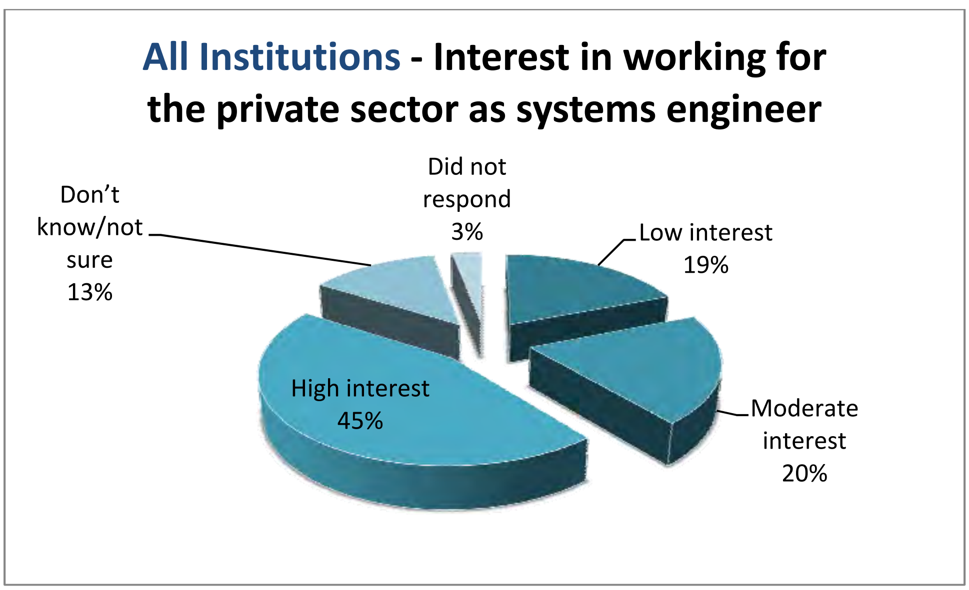
Working for the government as a systems engineer

Forty-two percent of the students reported that they might want to work for the government as a systems engineer; 24 percent said they had little interest in doing so, and 21 percent said they had interest (21%). 11 percent were not sure.



Working in private sector as a systems engineer

Forty-five percent of students reported wanting to work in systems engineering but in the private sector, while 20 percent showed only moderate interest in this and 19 percent expressed little interest.



Students without expressed interest in systems engineering

There was a small population of students (8 percent of all students) who were "Not at all interested" in pursuing systems engineering careers, either in the government or private industry. Some of their reasons included wanting to work as an engineer, but not as a systems engineer, in their particular branch of the military; attending business or graduate education in their engineering discipline; or planning to work for themselves as business consultants or entrepreneurs.

Career interests of Systems Engineering majors
Of the subpopulation of Systems Engineering majors (n=65),over half expressed high interest (4 and 5 on a scale of 1 to 5) in becoming systems engineers. These students reported a similarly high interest (4 and 5 on a scale of 1 to 5) in working for the government or private industry as a systems engineer.

Students with high interest in systems engineering careers in government and the private sector
Finally, there was a subpopulation of students (n=25), or about 10 percent of the entire student population who answered "highly interested" to all three questions. These students came from ten different institutions, including five service academies and five civilian universities, and five different disciplines (Systems Engineering; Alternative Energy Technology; Industrial and Software Engineering). Their post-graduation plans included "going to department head school"; working in private industry as a systems engineer; working in their particular branch of the military as a systems engineer; working in alternative energy; or pursuing systems engineering education at the graduate or doctoral levels. Sixteen of these 25 students were graduate students, 6 were undergraduates, 2 were postgraduates, and one identified as a PhD doctoral student.

X Student Outcomes and Assessments

As noted above, both project-created and institution-created assessments are being used to assess student outcomes. The project assessments were developed by the research team and are being administered to all students in all courses in all universities. The internal assessments were developed by each university to assess its particular course or capstone experience.

The first external (or common) assessment instrument, administered before the students began any coursework, was the survey that gathered information about the students' backgrounds, interests, and prior experience with systems engineering, asked them about their career aspirations, and then asked them five open-ended questions designed to assess their understanding of what systems engineering is and of systems engineering careers. The post-course survey includes several satisfaction questions and then repeats the same five open-ended questions.

The second external assessment has been designed to see the extent to which students have integrated systems engineering concepts into their thinking by asking them to transfer that thinking to another situation. Before they began any substantive course work, students were presented with a summary of the research and development history of the Bradley Fighting Vehicle platform, along with a few short clips from *The Pentagon Wars*—a fictionalized film version of the book by the same name—to engage students during the additional time commitment needed for this type of assessment. Students were asked to read and discuss the scenario and then respond individually to a single prompt: *“Could the problems encountered in developing the Bradley Fighting Vehicle have been avoided? Explain your answer.”*

Faculty were provided with a link to the results and were encouraged to use these to begin a discussion of the role of systems engineers in large-scale complex projects such as they were about to embark upon. The same material is then presented as a post-test, with the expectation that the responses will be more detailed and will show greater evidence of systems engineering thinking after the SE Capstone experience.

The following table details the external assessments completed, and the internal assessments developed, by institution:

	RT-19 COMMON EXTERNAL ASSESSMENTS			
	Using blogging tool	Pre-survey	Pre-case study	INTERNAL ASSESSMENTS
Auburn University	Yes [student's journal w/reflections]	Yes	Yes	Homework assignments, case study, mid-term exam, final exam.
Missouri S&T	Yes [PhD students and mentors' reflections on students' progress]	Yes	Yes	Presentations performed for mock reviews. Components of the final written project document used to evaluate progress.
Penn State	Yes [student's journal w/reflections]	Yes	Yes	Pre/post surveys (additional questions).
SMU	Yes [student's journal w/reflections]	Yes	Yes	Course assignments.
Stevens Institute	One entry as a test	Yes	Yes	Peer assessments. Rubric developed for overall project will be applied in Spring.
UMD	Yes [students’ journals w/reflections]	Not yet	Not yet	Lab assignments. Instructors' observations. Final project presentation.

UVA	Yes [UVA's Sakai Platform] [student's journal w/reflections]	Yes	Yes	Presentations, team reports. Design Process Knowledge Critique
Wayne State	Yes [Wayne State's website] [student's journal w/reflections]	Yes	Yes	SE Student Query, Interview, and Response Tool [SE-SQUIRT]. Team designs--final report.
AFIT	Not yet	Yes	Yes	Class assessment associated with introductory SE course. Presentations [e.g. design reviews]. Final thesis project.
NPS	Not yet	Yes	Yes	Currently developing formative and summative assessment instruments related to SE learning.
Naval Academy	Yes [PI's journal on project's progress]	Not yet	Not yet	The only assessment was that contained within the DAU courses.
Coast Guard Academy	Yes [posts of documents developed for project]	Yes	Yes	Assignments such as requirements specification, preliminary design reports, oral progress reports.
Military Academy	Not yet	Yes	Yes	Initial client meeting, Initial progress reviews, client out-briefing, peer assessment, interim tech report.
Air Force Academy	Yes [student's journal w/reflections and posts of documents developed for project]	Yes	Yes	The majority of the grading elements were taken from three team presentations. [guests from industry and outside faculty were invited to critique the teams' presentations].

At the time RT-19 interim reports were submitted in January 2011, no university had completed an analysis of student learning outcomes resulting from its course(s). Anecdotal information, in the form of student blog posts and comments from external mentors, suggest that the SE Capstone courses are impacting student learning, interest in DoD problems, and future SE education and careers.

Excerpts of such anecdotal evidence, below, are included only to provide an illustration of the types of impacts the SE Capstone courses are having. They are not intended to provide evidence of a pattern or of project-wide impact.

<u>Excerpts from student blog posts</u>

Week 1
“This week I met and introduced myself to my team members and we learned some of the principles of systems engineering. This was done by in class lectures and by examining a case study of the Bradley Fighting Vehicle.”

“The systems engineering competencies that we learned and applied this week were: stakeholders’ requirements, definition, requirements analysis, and technical planning. In class we did an exercise where we used stakeholders’ requirement definition and requirements analysis. In the exercise we looked at examples of what a stakeholder requirement would be. Then the requirement was interpreted to exactly what it might mean in engineering terms. The case study of the Bradley Fighting Vehicle showed the things that could happen if there is poor technical planning.”

Week 7
“This week was just plain awesome. Our team was able to finalize our Risk Mitigation plan which was pretty helpful in identifying some areas of our system that we hadn't necessarily considered before. When discussing some of the questions we had with the Comms team as well as [our mentor], we found that pursuing a WiFi network instead of a cell network would be the more viable option for conceptual purposes, with the understand that a fully implemented system would need a more powerful and capable network such as micro-cell.”

“Some of the systems engineering areas that we focused on this past week included things like Risk management, architecture design, and decision analysis. They were helpful in the fact that they put value to how engineers should go about weighing the pros and cons of risks in determining how vital they are in relation to other risks that may arise when solving problems of a system.”

Week 12
a. What did you and your team accomplish this week?
“This week, we ordered our printer/scanner and external hard drive for the LSA system. We also revised our schedule, and finished our critical design report. We present our critical design, as well, to the faculty, and they gave us feedback and made us think about certain areas problems could arise and what we should do about them.”

b. Which systems engineering competencies best align with what you did this week?
“Interface Management, Professional Ethics”

c. What specifically did you do in terms of each of the competencies you checked?
"Interface Management - we have begun thinking about and verifying how our interfaces will align with that of the Comms team, since we are using their network. It was determined that we will be able to communicate voice information of their system. Professional Ethics - In class, we talked about standards and codes, and how ethical situations can occur in the workplace."

Final Blog
"I feel that the things I learned about systems engineering had a large impact on my project. I was not aware of the amount of types of documentation that a systems engineering project required. The different competencies like requirements management and verification and validation showed how important organizational aspects are to a successful project. I think they resulted in a higher quality project."

"I think systems engineering is different than the design process I was used to because systems engineering focuses more making sure that the system accomplishes what is required of it. The design process I was used to often consisted of simply accomplishing the goal by any means."

"The advantage of a multidisciplinary team is that we can pull our knowledge from our disciplines to advance our project. However, because the project got focused down, one group member was relied upon more heavily than the others. The most difficult task to execute was the risk mitigation plan because nobody in the group was certain about the actual risks."

"A systems engineering course would be good for someone completing a project because it introduces several different design considerations like risk and requirements. This will enhance the design of the project."

"Systems engineering would be a good career because of the potential to work on several different types of projects, not just the projects in your discipline. You will also get to work with several different types of engineers."

<u>DoD Mentor Feedback:</u>

The following is an email from a DoD mentor on impressions of course impacts on the students:

"Our first semester with Penn State was a great success! We sponsored four projects, one within each of the Prepositioned Expeditionary Assistance Kit capability areas (water purification, power generation, local situational awareness and communications). Each of the teams produced a functioning prototype that met or exceeded the objectives established at the beginning of the semester. I recently attended the Fall Engineering Showcase where each of the projects was displayed and evaluated. The Local Situational Awareness and Communications teams were recognized as the top two projects in the Systems Engineering category. Seventeen students participated in the

DDRE sponsored projects. At least two have expressed interest in pursuing SE Masters degrees this next year and more in the future. Several of the students are graduating and three will be entering the workforce in Defense related positions. Also, PSU has asked that we sponsor projects again in the Spring Semester."

Myself and Mr. Phil Stockdale,Technical Manager for the PEAK JCTD, are reviewing the project deliverables with our SMEs and will incorporate them into the PEAK JCTD or other projects as applicable. The objective of the PEAK JCTD is to demonstrate and transition an array of capabilities that can be pre-positioned to help provide essential services in time sensitive events. PEAK will provide these services to local responders and the local populace in support of a wide variety of missions, to include support for humanitarian assistance/disaster relief (HA/DR) activities.

COL Nancy Grandy
DDR&E/Rapid Fielding Directorate
Mentor to Penn State University Capstone Team

XI DoD and Industry Mentors

Nine of the PIs reported that they had DoD mentors, but four of the five who did not were military institutions. Six of the PIs reported that they had industry mentors, but only five institutions reported that they had both as of the end of the fall semester. However, many of these were pre-existing relationships and the mentor process was uneven in its degree of effectiveness, as the following sections describe.

The following table includes information by institution:

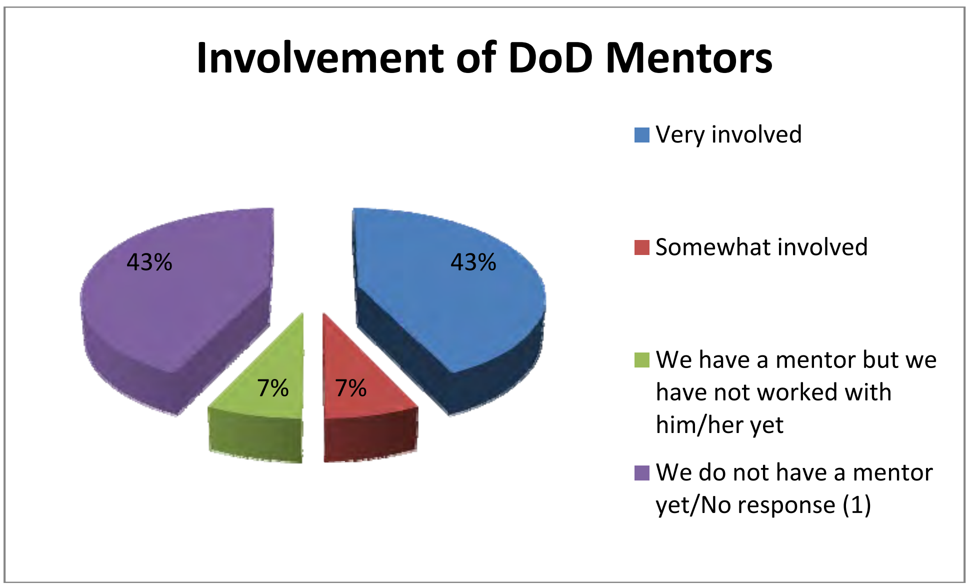
	DoD	Industry	
Auburn University	N	N	No DoD or industry mentors during fall semester; plans for recruiting both DoD and industry mentors during spring semester
Missouri S&T University	Y	Y	1 DoD mentor, Pete Mueller, from Office of Naval Research; 5 industry mentors (systems engineers) from the Boeing Company
Penn State University	Y	N	2 DoD mentors (Col. Nancy Grandy, Oversight Executive (Joint Logistics) Office of Deputy Undersecretary of Defense Rapid Fielding Directory; Phil Stockdale of National Defense University); no industry mentor but student teams used a university-employed collaborator who formerly worked at Honeywell International

Southern Methodist University	Y	N	1 DoD mentor from Marine Corp. Base served in a recruitment capacity; 4 DoD clients from Marine Corp base visited institution to deliver specs for project; no industry mentor
Stevens Institute of Technology	Y	N	Number of DoD mentors not specified; no industry mentors
University of Maryland	Y	Y	DoD mentors at Aberdeen Proving Ground and Army Research Lab (number not specified); 1 industry mentor, Sandy Friendenthal, from Lockheed Martin
University of Virginia	Y	N	1 DoD mentor, Bill Campbell, used as SE subject matter expert; 2 DoD clients for water quality testing team: Col Nancy Grandy, Oversight Executive (Joint Logistics) Office of Deupty Undersecretary of Defense Rapid Fielding Directory; Phil Stockdale of National Defense University; 1 DoD client for medical training simulator team, Dr. Alan Liu of the National Capital Area Medical Simulation Center (SImCen) of the Uniformed Services University of the Health Sciences (USUHS) ; no industry mentors
Wayne State University	Y	Y	2 DoD mentors, Ms. Claudia J. Quigley of Natick Labs, USA AMC, & Dr. Peter Schihl, Chief Technologist-Mobility at US Army TARDEC; 3 industry mentors from Mechanical Engineering Industrial Advisory Board (IAC)
AFIT	Y	Y	Air Force Research Lab subject matter experts used as DoD mentors (no number specified); industry mentors from Cooperative Engineering Services, Inc. (CESI) & CLMax, a UAV design and fabrication business (number not specified)
NPS	N	N	No DoD or industry mentors during fall semester; plans for recruiting both DoD and industry mentors during spring semester
USAFA	N	Y	No DoD mentors; recently established ties with industry mentors from two companies: Greenvolts (solar industry) and Schweitzer Electronics (power industry)

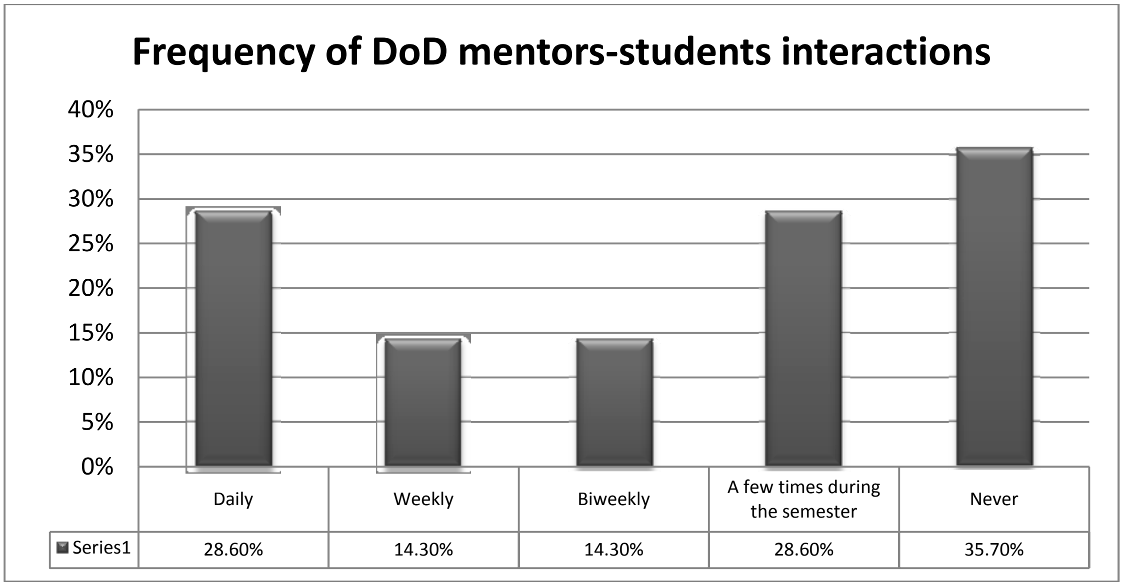
USNA	N	N	No DoD or industry mentors
USMA	Y	Y	1 DoD mentor/client, LTC Joe Nolan; recently established ties to industry mentor Sarnoff
USCGA	N	N	No DoD or industry mentors

<u>DoD Mentors</u>

Even PIs who had DoD mentors reported very different levels of interaction with them. Despite efforts on the part of the DoD, several had not been assigned or connected with projects at the time of submission of the interim reports. Thus while over 46 percent of the PIs reported that their DoD mentors were "very involved," another 46 percent reported not having a mentor or not yet working with their mentor:



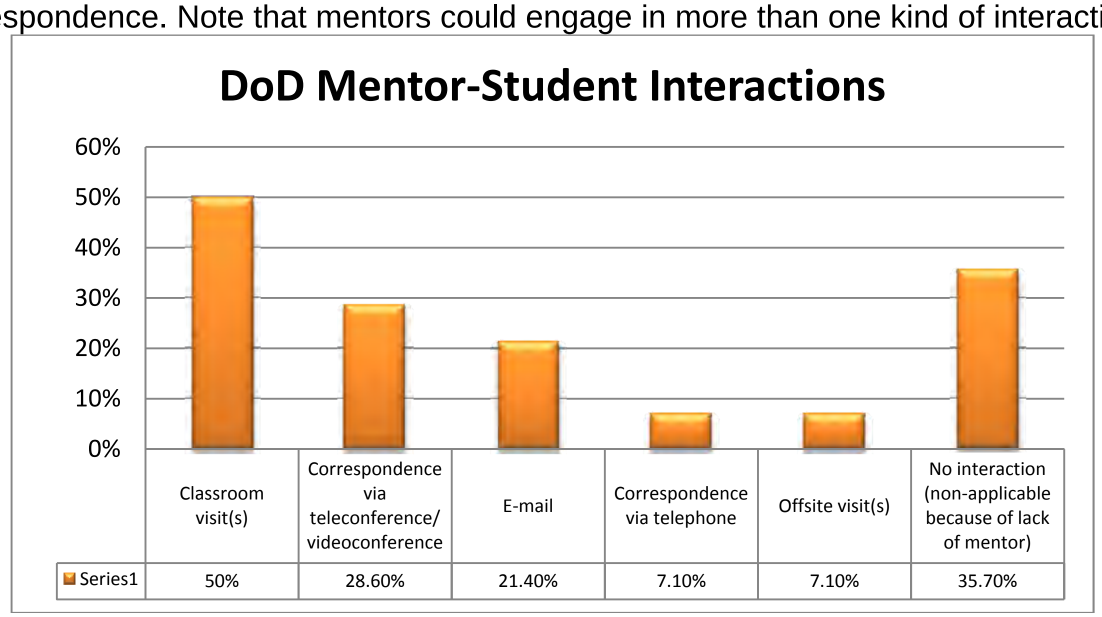
Some PIs reported that their mentors were playing an "active role in meeting…by phone, email and VTC," while others reported that the mentor had not followed up with the students after some initial communication. Over 30 percent of the PIs reported that DoD mentors communicated several times a semester with students, and 36.4 percent reported that they did so on a weekly or biweekly basis. One PI even reported having daily interaction:



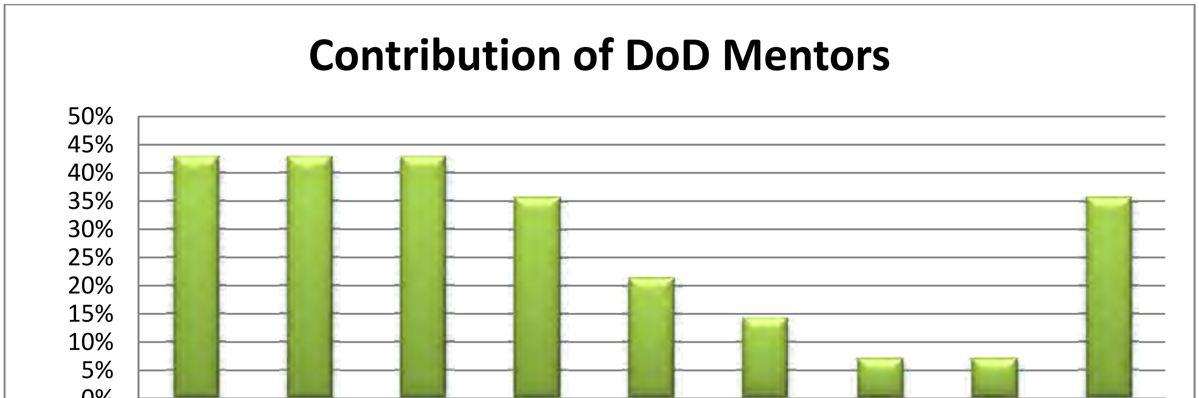
Like RT-19 faculty, DoD mentors facilitated student learning in a variety of ways; however, their roles differed instructionally depending on whether they also served as clients, as they did for 50 percent of participating institutions. Some of their roles included:

- Providing feedback on student projects and deliverables
- Providing technical expertise
- Attending student presentations
- Facilitating field trips offsite to manufacturing or design sites where students could observe engineering processes related to their projects

Mentors with the highest level of student engagement interacted with students in every single activity area and with frequency, while others provided only intermittent correspondence. Note that mentors could engage in more than one kind of interaction:



The PIs therefore differed in their evaluation of the mentors’ contributions to student learning and engagement. Note that mentors could play make contributions in more than one area:



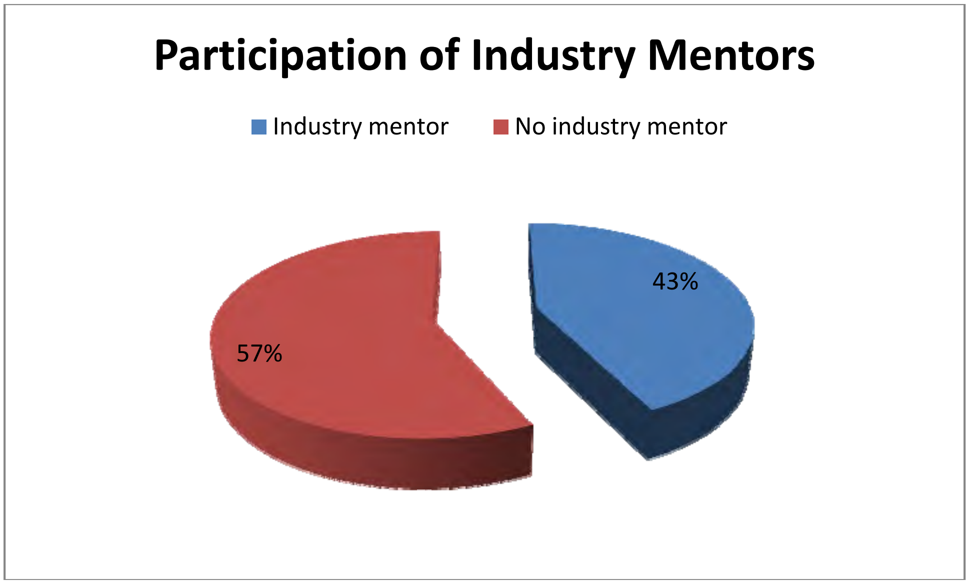
	Motivation for students	Feedback on student projects	Technical expertise	Client requirements (the mentor is also the client)	Initial on-site visit to campus	Access to sites	DoD mentor has not been easily accessible to students and did not provide support or advice of great value	DoD mentor initially motivated students but did not follow up with further consistent communication	No engagement (non-applicable because of lack of mentor)
Series1	42.90%	42.90%	42.90%	35.70%	21.40%	14.30%	7.10%	7.10%	35.70%

One PI reported that their DoD expert was “outstanding,” having developed a seminar for students and worked with them on prototype evaluations. Others stated that their mentors demonstrated up-to-date technologies in the students’ problem area; offered “invaluable comments and direction” for student projects; and played an “active role” by monitoring project progress through multiple communication channels.

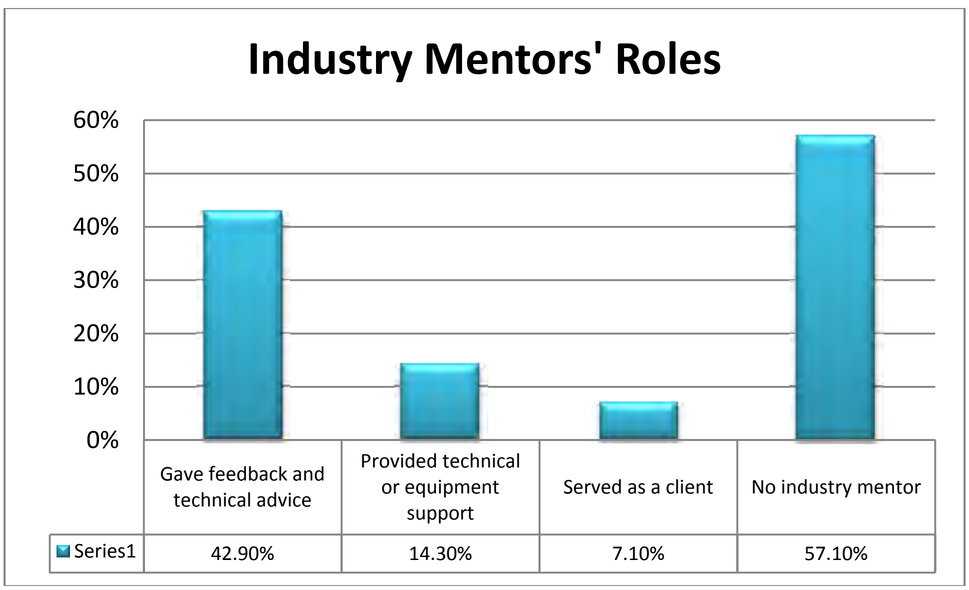
However, PIs from two institutions described their relationship with the DoD mentors as “unsuccessful” due to communication breakdowns brought on by personnel changes on the mentors’ end and another wrote that although the DoD mentor had provided initial motivation for students by visiting the classroom, there had not been much communication as the semester progressed because of the mentor’s distance and time/scheduling constraints.

<u>Industry Mentors</u>

About 60 percent of the PIs reported not having an industry mentor. Three reported that they planned to work with an industry mentor during the spring semester.



Industry mentors took on roles similar to the roles played by DoD mentors—as clients, consultants, or SMEs. Note that mentors could play more than one role:



PIs at two institutions that had both industry and DoD mentors reported that having both types of mentor benefited the students' projects. For example, one PI reported that the DoD mentor acted as a client while also offering occasional help with analysis and understanding system requirements, while the industry mentor acted as a consultant "educating [students] on their technical approach." The other PI whose team included both types of mentors described the industry mentor as "part of the project teams…intimately involved with [students'] day to day progress and project management aspect," compared with the DoD mentor, who took the customer's perspective and dealt more with design and engineering concerns.

At another institution, however, a PI expressed dissatisfaction with the mentor's overlapping roles of client and project advisor/consultant and argued for better defined responsibilities. Initially regarded by students as a "customer" or "major stakeholder," the DoD mentor functioned in reality as a subject matter expert who assisted students with the design process.

XII Effectiveness of Course Design--Preliminary Observations

The ultimate measure of effectiveness of the course design will be determined by the student outcomes identified as project goals:

- Increase student learning of SE competencies
- Increase student interest in DoD problems/careers
- Increase career interest in SE study and careers

It is premature at this stage of course implementation to correlate student outcomes with the structure or content of the courses or with any particular strategies or course materials. However, the PIs' interim reports provide some insights into preliminary lessons learned about course objectives and implementation. These observations fall into several categories:

1. Challenges teaching the broad topic of systems engineering to non-SE majors under time constraints.
2. Challenges with equivalent grading policies in multi-disciplinary teams, particularly where SE was an overlay to an existing multi-disciplinary team structure.
3. Challenges with content-domain-specific problem areas and with finding meaningful ways for other disciplinary majors to contribute.
4. Motivating external mentors to bring authentic professional experiences to the learning experience.
5. SE content modules provide opportunities to bring non-SE majors to a common understanding. These have been implemented with varying frequency, durations, and numbers across several projects.
6. Where possible, the integration of DAU modules provide additional incentives for students to gain desirable certifications, but scheduling common experiences for students to take these modules impacted completion.

And in some cases, the challenges identified were common to the formation and operation of effective, multi-disciplinary teams:

7. Provide subject matter expertise (internal and external) to infuse sufficient disciplinary knowledge such that students may focus on the bigger SE competencies.

Excerpt of Pilot University Interim Report

"The biggest challenge early in the course was getting the groups formed and communications established while mixing both distance and local students. Unlike other undergraduate courses, the design project for this course not only involved a high level of detail but also included an interdisciplinary approach. This made some of the students uncomfortable with the deliverables of the project. This was overcome by providing subject matter experts from both the assisting faculty and industry to assist the groups in areas that their members did not have expertise. In this way, the students were able to focus more on the systems engineering approach and less on the details of their particular engineering disciplines."

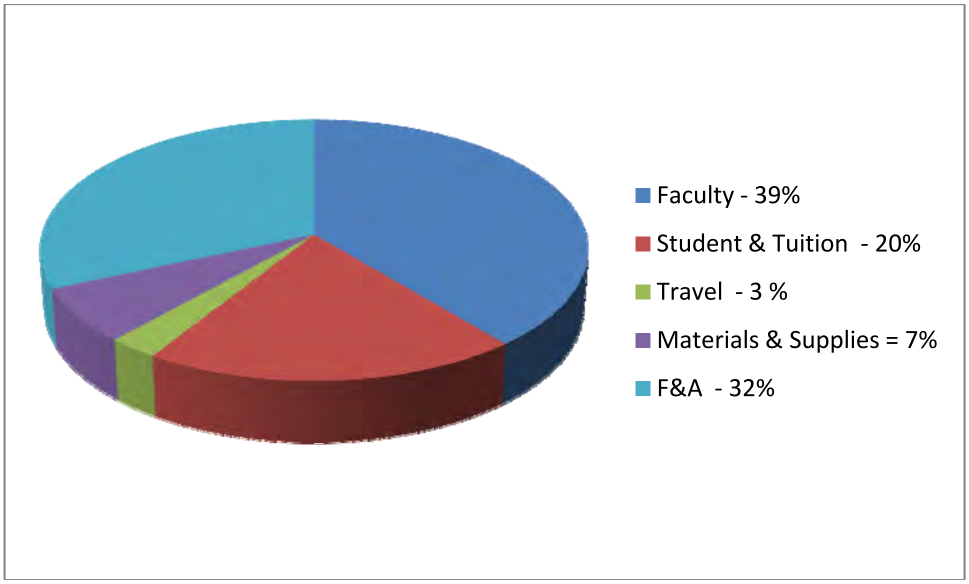
It is also not clear at this stage the extent to which RT-19 funding has created entirely new materials or simply (and in some cases, substantially) enhanced existing courses. This is an area for further investigation. Several institutions indicate that this funding has provided the capital to design a coherent course sequence or to build additional courses, but more information is needed to measure such impacts across the range of participating institutions.

XIII Allocation of Resources

At just beyond the mid-point of project implementation, it is noteworthy that, as at Dec. 31, 2010, only 30% of subcontractor budgets have been expended. Preliminary analysis points to several possible explanations:

1. Lag time in billing for expenses
2. Lag time resulting from delayed awarding of Phase II and the challenges involved with Phase II being awarded in two segments (a and b). Phase II a was awarded May 15, 2011 (with a completion date of July 31, 2010) and Phase II b was awarded June 25, 2010. The slow release of the funding to the collaborator universities proved challenging administratively to these institutions resulting in a late start for billing.
    a. With the exception of one collaborator university, invoicing against the project started August 2010 while actual work had been started May when their subcontract was issued.
3. Time estimated for faculty effort for course development during summer 2010 could not be charged to RT-19 budgets due to other project commitments
4. Summer 2010 labor that was used to develop the coursework was not charged to the project; the labor budget was reallocated to the spring semester (Jan. – May 2011) when the more significant portion of the work will be done.

Upon examination, of the total subcontractor budgets, the following represents the expenditure categories:



While the original level of funding per institution (approximately $200,000 per institution) is on par with curriculum and course development funding levels from other agencies[§], this is an area that will be analyzed further when the final project report is submitted.

Analyses of student impacts (degree of growth on pre-/post measures of learning and SE career interest and knowledge/interest of DoD problems) across the projects, as well as the numbers of students impacted are also factors that should be used to assess the appropriate allocation of financial resources, as some institutions impacted as many as 54 students, while others impacted as few as five.

XIV Dissemination

To date, the following dissemination has taken place:

- A presentation on RT-19 was made at the Annual SERC Research Review in College Park, Maryland on November 10, 2010.
- Six draft papers have been submitted to the American Society of Engineering Education (ASEE) 2011 Annual Conference in June 2011, as follows:

[§] At the time the budget recommendations were made for RT-19 the National Science Foundation Course, Curriculum, and Laboratory Improvement (CCLI) program awards grants with a ceiling of approximately $200,000 for course development efforts.

#	2011 ASEE – SECC Abstract Title	Authors/Institution
725	SE Capstone: A Pilot Study of 14 Universities to Explore Systems Engineering Learning and Career Interest through Department of Defense Problems	SERC/RT-19 Research Team
1077	SE CAPSTONE: Introduction of Systems Engineering into an Undergraduate Multidisciplinary Capstone Course	Penn State University
1206	SE CAPSTONE: Implementing a Systems Engineering Framework for Multidisciplinary Capstone Design	Stevens Institute of Technology
1211	SE Capstone: Integrating Systems Engineering Fundamentals to Engineering Capstone Projects: Experiential and Active	Wayne State University
2186	SE CAPSTONE- Introducing Multidisciplinary Design to USCGA	US Coast Guard Academy
2669	Fostering Systems Engineering Education through Graduate Capstone Projects	Air Force Institute of Technology

Further, SE Capstone partner universities are encouraging the submission of student posters to two April 2011 events:

- April 12-14, 2011: 12th Annual Science & Engineering Technology Conference/DoD Tech Exposition, North Charleston, SC

- April 29, 2011: 2011 IEEE Systems and Information Engineering Design Symposium, Charlottesville, VA

XV Recommendations

At this stage of project implementation, there are several prevalent themes that have been identified to improve the course implementation. These have been culled from interim reports submitted by PIs and observations by the research team include:

1. More planning time is needed to effectively plan and coordinate course materials and assessments, the availability of external resources such as DoD and industry mentors, as well as facilities visits, and to secure buy-in and define roles and responsibilities of interdisciplinary faculty participants.

2. In order to effectively recruit students, the specific DoD problem area should be defined and disseminated to students at least at the time students register for their next cycle of courses.

3. Better connections, more clearly defined roles, and stronger commitment by DoD and industry mentors would enhance students' experiences where the participation of external mentors has been lacking. Consideration of a nominal financial commitment by external clients may increase the investment/commitment by these mentors.

4. A list of required and recommended faculty events and student programs should be made available to PIs to encourage maximum participation and sufficient financial resources.

XVI Future Reports and Future Research

As indicated throughout this document, the preliminary observations and findings represent only a snapshot of the richness of the 14 SE Capstone courses that have been and are being implemented by partner institutions. One significant limitation of this report is that no comprehensive analysis of student learning has been conducted at this stage of course implementation. The final report will aim to connect the course content and organization, including materials created by faculty as well as the contributions of external mentors, with impacts on student learning of SE content, their interest in SE careers, and their interest in DoD problem areas and careers.

As noted in the introductory section of this report, this research has been undertaken in order to inform the development of a larger capacity-building and scale-up effort that could substantially increase the SE workforce available to DoD and industry in the next decade and beyond. RT-19 will capture methods, strategies, and tools that have led to desired student outcomes. Further research to translate these findings into methods, tools, and processes that can be operationalized in new universities has been proposed.

Appendix 1: Detailed List of Course Descriptions, Problem Areas, and Types of Student by Institution

Institution	Course/Project	Description	DoD Problem Area(s)/Focus	Students
Auburn University	Systems Engineering in a Secure Computing Intensive Environment	1st course [Fall 2010] is a broad-spectrum overview to systems engineering. It introduces major concepts using a case study of the security architecture of two open systems under consideration by DoD. 2nd course [Spring 2011] is an actual project employing low-cost, open-source, secure computing. The students will demonstrate secure collaboration using the Android open source software stack.	Problem Area 1 Improvement of computer systems to enable secure data sharing among complex systems at low cost. Course material for the 1st course will be delivered through presentations by speakers from industry and government; lectures, and interactive student activities. The 2nd course is a hands on sequel in which students will complete their defense-focused capstone project.	3 U 30 G 17 persist to 2nd course Includes: CS, IE, and EE On-campus and distance education
Missouri S&T University	Agile Systems Engineering- Active And Experiential Learning Approach	1st Course [Fall2010]: Introduction to Systems Engineering provides the student with basic understanding of main concepts, tools, and processes of systems engineering. 2nd Course [Spring2011]: Physical Artifact Creation and Validation. Development of detailed design for a wireless haptic vest with embedded sensors. Students will focus on the wireless tech to	Problem Area 4 Immersive Training Technologies. Subtle simulation of real battlefield scenarios. Operational scenarios simulate getting shot, getting hit, and minor restriction.	10 U 19 G Includes ECE, ME, and AE On-campus and distance education

		activate embedded sensors and mechanical components.		
Penn State University	Interdisciplinary Capstone Design Project	This is a one-semester course/project [Fall2010]. Eight modules delivered by systems engineering faculty. Projects are completed using the Bernard M. Gordon Learning Factory, a lab providing modern design, prototyping, and manufacturing facilities.	Problem Area 2 Expeditionary Assistance Kit. 1. Water purification system 2. Power generation from renewable energy sources 3. Local situational awareness system 4. Global low-bandwidth communication unit	17 U Includes BE, CE, EE, ME, IE
Southern Methodist University	Leveraging Interdisciplinary Teaching Environments to Research Immersive Training Environments	1st Course [Fall2010], students work in interdisciplinary teams to design an architecture solution that meets customer specifications. Winter break: 10 days Skunk Works Immersion Design Experience. (IDE) 2nd Course [Spring 2011], students will continue to work on interdisciplinary teams to build and test a prototype of their design.	Problem Area 4 Immersive Training. The objective is to improve existing capabilities in three areas: (1) fidelity of motion capture systems, (2) reduction of infrastructure required for team based motion capture, and (3) high resolution facial expression capture and replication	11 U Includes CS, EE and ME 3 PhD students serving as teaching assistants
Stevens Institute of Technology	Building Education and Workforce Capacity in Systems Engineering	Implementation of SE in capstone senior design course (two semesters): a series of 6 Systems Engineering all-day workshops are being delivered to introduce SE principles and methods to all	Problem Area 3 Green-Expeditionary Housing. For a 100 person FOB and 3-6 months deployment. Modular housing with micro-grid support for alternate energy	17 U 7 G Includes EM, ME, EE, CE, Civ Eng, A&T

	through Capstone Design	students. Modifications made to adjust to scheduling constraints. Design component of capstone project starts in Spring 2011.	sources, including low impact solutions for waste and water.	
University of Maryland	Special Topics in Systems Engineering	This is a one semester course that is offered twice over one academic year. The goal of this pilot is to introduce students to SE thorugh a hands-on project experience.	Problem Area 1 Focuses on low-cost, low-power computers leveraging open source technologies. Supports integrated wireless sensor networks, black box design, and particle steering using micro fluidic devices.	15 U Fall; 4 teams 38 U Spring Includes EE, CE, BE. [assisted by 4 G]
University of Virginia	Extensible Systems Engineering Capstone Experience	Course exposes students to the entire systems engineering process via two interdisciplinary capstone projects over one academic year. During the 2nd semester the two teams will test and evaluate each other's projects.	Problem Areas 1 and 4 Project #1 involves a virtual reality system for medical training. Project #2 is focused on developing a mobile, autonomous, water quality testing system.	17 U Includes SE, ME, CS, BE, ECE 2 SE G students provide technical support

Wayne State University	Integrated Material Design and Realization for HA/DR Kits	This project integrates SE product development concepts across 4 courses at the undergraduate and graduate level. 1 Full semester course (Winter 2011) plus modular insertion into multiple other courses (start process – Sept 2010).	Problem Areas 1and 3 Expeditionary Operations. The projects will be focused on development of elements of HA/DR kits, such as solar oven, water purification system, alternative energy.	10 U 19 G Includes ME, ISE
Air Force Institute of Technology	Introduction to Systems Engineering Process and Design	This course [one academic year] provides a broad introduction to a systematic approach necessary for the formulation, analysis, design and evaluation of complex systems. Technical support provided by the Autonomous Navigation Technology Center associated with the Department of Electrical and Computer Engineering	Problem Area 1 Low-power computing for operations in austere environments. Development of a novel hybrid electric UAV for near silent, long loiter, low energy operations.	5 G Mix of AE, SE
Naval Postgraduate School	Transforming Graduate Education in Systems Engineering	A series of 8 core SE courses [one academic year]in the masters curriculum taught via team based pedagogy, with the capstone project integrated into the entire curriculum as a carry through, hands on experience. The courses provide a holistic span of education from systems thinking, , quantitative analysis, through system design and production	Problem Area 3 Expeditionary Operations and HA/DR Assistance Kits. Development of novel, low density power supplies, advanced materials with low thermal and visibility properties, low signature communication devices. [Project starts in January 2011].	48 G SE

US Air Force Academy	Capstone Design Project	This project integrates sequentially two SE courses over one academic year. Students will learn to successfully work in a multidisciplinary team, to apply SE and management tools, communicate project details, and evaluate contemporary military issues.	Problem Area 1 Low Power Computing A 10 KVA solar energy system for deployed operations. The end system will incorporate smart grid technology to facilitate control and integration [Project starts in spring semester].	7 U Includes EE, CE, ME, SE
US Naval Academy	Principles of Engineering Systems Design	The senior design capstone course [one academic year] is enhanced with additional SE sections based on experimental coursework. Enhancements include independent study course based on Defense Acquisition University courses leading to certification opportunities.	Problem Area1 and 2 Expeditionary Ops. Portable, low power water purification. Portable, renewable power generation, storage and distribution [most of the project-centric work is done in the spring semester.]	16 U Includes EE, CE, NA, OE
US Military Academy	Systems and Engineering Management Design	This capstone course [two sequential courses over one academic year] emphasizes SE in technology based organizations. Cadets examine interconnections between planning, organizing, leadership, control, and the human element in production, research and service organizations	Problem Area 4 Immersive Training Augmented Reality: synthetic environ, decision analysis for optical & video displays, high fidelity tracking.	4 U Includes SE, EM, and OR
US Coast Guard Academy	Systems Engineering Capstone	This course [one academic year] incorporates critical elements of SE. Cadets will have regular	Problem Area 1 Expeditionary Ops. Green Power Generation HA/DR	24 U Includes

	Enhancement	contact with external customers [USCG Shore Maintenance Command and USCG Aviation Logistics Center] and must defend their work at preliminary and final design reviews	Portable hull inspection system. Green electric power in remote hot climates. In water remote propeller cleaner. Hybridization system for fleet vehicles.	Civ Eng, EE, and ME

NOTES:

1. Sources include proposal documents submitted by universities, interim reports, and a summary prepared by R. McGahern for a presentation at the 2010 Annual SERC Research Review conference Nov. 9-10, 2010.
2. The number of students shown in the table above include only those who are directly involved in the whole capstone experience [coursework +project].
3. Abbreviations : U: Undergraduates, G: Graduate Students, EM: engineering management, CE: computer engineering, Civ Eng: civil engineering, EE: electrical engineering, NA: naval architecture, OE: ocean engineering, AE: aerospace engineering, A&T: arts and technology, OR: operations research, IE: industrial engineering, ME: mechanical engineering, CS: computer science, SE: systems engineering, BE: biomedical engineering, ECE: electrical and computing engineering, ISE: Industrial & Systems Engineering

Appendix 2: Detailed List of Course Content and Materials

Partner Institution	Course Materials
Auburn University	SE Lecture topics: conceptual design, preliminary design, detail design, testing, open source computing systems, acquisition, security certification, systems security, decision analysis, configuration management, economics, real world systems engineering. Standards: National Information Assurance Training Standard for Senior Systems Managers. Course management system: Blackboard™ Software applications: I-CAIV [decision analysis], Eclipse & Papirus [SysML diagram] Archive of video recorded lectures [for students viewing]
Missouri S&T University	SE Lecture topics: system definition and concepts, requirements and specifications, dynamic object-oriented requirements system [DOORS] presented by BOEING mentor, functional analysis and decomposition, quality function deployment [QFD], conceptual systems design, DoD architecture framework, risk identification/management, Sys Eng planning , architecture evaluation, manufacturing and disposability, supportability, economic evaluation, preliminary design review, reliability, system test and evaluation, trade off studies, modeling and simulation, detail design, optimization in design and operations, writing specifications. Standards: PMT 90-S002K Multiple Integrated Laser Engagement System [MILES] Communication Code [MCC] STANDARD. MIL-STD-882D DoD Standard Practice for System Safety.
Penn State University	SE Lecture topics: systems engineering fundamentals, systems requirements analysis and allocation, systems architecture, problem solving in system design, decision and risk analysis, introduction to project management, systems verification and validation, introduction to systems thinking Reference material: NASA Systems Engineering Handbook, 2007 Course management system: ANGEL [Penn State Management System]
Southern Methodist University	SE Lecture topics: overview of systems engineering, problem definition and requirements, engineering design process, incremental commitment model [ICM]. These joint SE lecture notes were complemented with specific separate lectures focused on CSE, ME, and EE Course management system: Blackboard™

Stevens Institute of Technology	6 all day work-shops to introduce students to key SE principles and methods. WS-1: Intro to the project, general overview of the SE process, and ConOps WS-2: System Level Architecture WS-3: Subsystem Level Architecture WS-4: Logistics and Life Cycle Support WS-5: Subsystem Integration and Test WS-6: System Level Integration Test Course Management System: Google Groups, Google Docs, Dropbox SE Software applications: Labview, Matlab, Solidworks
University of Maryland	SE Lecture topics: introduction to systems engineering, strategies of SE development, foundations for model-based systems engineering, modeling system structure and system behavior, object and component based development, multi-objective trade studies, requirements engineering, systems engineering with UML and SysML [Sandy Friedenthal from Lockheed Martin delivered a special lecture on SysML, which was recorded], system level design, basic approaches to system validation/verification, basic approaches to system validation/verification. Course management system: UMD's Institute for Systems Research-Website SE software applications: ParaMagic™ v16.6 sp1, Matlab/simulink
University of Virginia	Project 1: SE Design-Rapid Adaptive Needs Assessment [RANA] Unit (1) - Problem Definition, Concept of Operations Humanitarian Assistance & Disaster Response (HA/DR). Unit (2) – RANA Kit and Decision Support Tool Requirements. Unit(3) – Alternatives and performance criteria. Unit (4) – Building and testing. Unit (5) – Policy Context Project 2: SE Design- Immersive Virtual Medical Training Capability. This project has 5 main stages: definition of the problem, drafting requirements, prototyping and implementation of the solution, integration, and validation in human-subjects. Course Management System: UVa's Sakai Platform
Wayne State University	Lecture topics: introduction to systems engineering, concept evaluation and selection, risk management in design The above SE principles and methods are complemented with the following courses: 1. Integrated Product Development – to educate students about the importance of concurrent and collaborative engineering in a global economy.

	2. Thermal-Fluid System Design – with emphasis on alternative energy tech Course management system: Blackboard™
Air Force Institute of Technology	Lectures topics: intro/process overview, conceptual system design and requirements definition, model based SE , utility theory, preliminary system design, detailed design and development, system test, evaluation & validation, reliability, maintainability & supportability, affordability, usability/human system integration. These topics were complemented by 3 case studies Standards: DoD5000, JCIDS, DAG Reference Material: INCOSE Handbook Course management system: Blackboard™ SE software applications: Enterprise Architect, LEGO Mind-storm robotics kits
Military Academy [West Point]	Lectures topics: systems thinking, stakeholder analysis, functional analysis, value modeling, value modeling workshop, in-progress review [IPR], modeling and simulation, VBS2 Lab, O*Net Analysis, alternative generation, solution enhancement.
US Air Force Academy	Lectures topics: Introduction to DFEC Capstone Design Course, Requirements development, planning and scheduling, functional analysis and allocation, risk management. Course management system: MS-Sharepoint Software applications: MS-Project, Crystal Ball
Naval Postgraduate School	The capstone coursework spans almost the entire core curriculum in the SE masters degree program. The RT-19 Project is fit into the lab sections of the following courses: Engineering Project Management, Systems Suitability, System Architecting and Design, Systems Integration and Development. The capstone is related to each of the other core courses as part of learning, application, and assessment. Course Management System: Sakai [NPS platform] Standards: Naval Educational Skill Requirements [ESR], specifically the 5800 ESR for systems engineering; ABET for SE; the CDIO initiative standards SE software applications: Vitech CORE
US Coast Guard Academy	Lectures topics: design process overview, problem definition and need identification, quality function deployment, concept generation, functional decomposition, evaluation [Pugh's matrix], codes and standards, human factors, design for manufacture, design for assembly & recycling, engineering economics, detail design, engineering ethics, modeling and simulation, risk-reliability-safety,

	quality-robust design-optimization Course management system: Blackboard Software Applications: Solidworks
Naval Academy	The schedule is based on completing the required DAU courses: Introduction to DoD Science and Technology Management, Fundamentals of Systems Acquisition Management, Fundamentals of Systems Planning, Research, Development, and Engineering. The discussions focused on how to apply the topics from the courses to the design process for the project of each Senior Design Capstone Team

Appendix 3: IRB Status as of January 2011

University	Local IRB approval granted or exempt	PI/Staff with IRB consents received
Auburn University	No	David Umphress, Alice Smith, C.W. Perr
Missouri S&T	Yes	Cihan Dagli
Penn State	Yes	James Nemes, Mary Lynn Brannon, Liz Kisenwether, Kirsten Hochstedt
SMU	Yes	LiGuo Huang, Nathan R. Huntoon
Stevens Institute	Yes	Keith Sheppard, Eirik Hole
UMD	No	Mark Austin
UVA	Yes	William Sherer, Reid Bailey, Greg Gerling, Garrick Louis
Wayne State	Yes	Darrin Ellis, Kyoung-Yun Kim, Dean Pichette, Ming-Chia Lai, Eugene Rivin, Yun Seon Kim
AFIT	Yes	David Jacques
NPS	No	Dave Olwel, Clifford Whitcomb, Ali Rodger
Naval Academy	Yes	Not yet
Coast Guard Academy	No	Richard Freeman, Ronald Adrezin, Jonathan Russell, Charles Hatfield
Military Academy	Yes	Steve Henderson
Air Force Academy	No	Andrew Laffely, Alan Mundy

References

[1] Rosato, D., Braverman, B., & Jeffries, A. (2009, November). The 50 best jobs in America. Money, 88-96.

[2] National Defense Industrial Association Systems Engineering Division Task Group Report (2006, July). Top Five Systems Engineering Issues within Department of Defense and Defense Industry.

[3] Top Systems Engineering Issues In Department of Defense and Defense Industry, July 2010. National Defense Industrial Association Systems Engineering Division. Retrieved January 1, 2011 from: http://www.ndia.org/Divisions/Divisions/SystemsEngineering/Documents/Studies/Top%20SE%20Issues%202010%20Report%20v11%20FINAL.pdf.

[4] Wegner, G. R.. 2008. Partnerships for public purposes: Engaging higher education in societal challenges of the 21st century. *National Center for Public Policy and Higher Education.*

[5] Fabrycky, W. J. 2010. Systems engineering: Its emerging academic and professional attributes. In *Proceedings of the 2010 American Society for Engineering Education (ASEE) Annual Conference and Exposition, Louisville, Kentucky, June 20-23, 2010.*

[6] Verma, D., J. Farr, and L. H. Johannesen. 2003. System training metrics and measures: A key operational effectiveness imperative. *Systems Engineering* 6 (4): 238-248.

[7] Jain, R., A. Squires, D. Verma, and A. Chandrasekaran. 2007. A reference curriculum for a graduate program in systems engineering. *INCOSE Insight, July* 10 (3): 9-11.

[8] Jain, R., K. Sheppard, E. McGrath, and B. Gallois. 2009. Promoting systems thinking in engineering and pre-engineering students. In *Proceedings of the 2009 American Society for Engineering Education (ASEE) Annual Conference and Exposition, Austin, TX, June 14-17, 2009.*

[9] Squires, A. and R. Cloutier. 2010. Evolving the INCOSE reference curriculum for a graduate program in systems engineering. *Systems Engineering* 13 (4): 381-388.

[10] Kasser, J., M. Frank, and Y. Y. Zhao. 2010. Assessing the competencies of systems engineers. In *Proceedings of the 7th bi-annual european systems engineering conference (eusec), stockholm, sweden, may 23-26, 2010.*

[11] Ferris, T. L. J. 2010. Comparison of systems engineering competency frameworks. In *4th asia-pacific conference on systems engineering (APCOSE 2010), keelung, taiwan, october 4-6, 2010.*

[12] Squires, A. 2011. *Measuring the Value of Remote Online Systems Engineering Education.* Thesis, Stevens Institute of Technology, Institution of Systems and Enterprises.

[13] Defense Acquisition University. 2010. SPRDE-SE/PSE competency model 4/14/10 version. https://acc.dau.mil/CommunityBrowser.aspx?id=315691&lang=en-US (accessed May 25, 2010).

[14] Burke, G. D., M.J. Harrison, R. E. Fenton, and P. G. Carlock. 2000. An approach to develop a systems engineering curriculum for human capital and process improvement. In *Proceedings of the 10Th Annual International Symposium, INCOSE 2000, Minneapolis, Minnesota, July 16-20, 2000.*

[15] Jansma, P. A. and R. M. Jones. 2006. Advancing the practice of systems engineering at JPL. In *Aerospace Conference, 2006 IEEE.*

[16] Verma, D., W. Larson, and L. Bromley. 2008. Space systems engineering: An academic program reflecting collaboration between government, industry and academia (open academic model) . In *Presented at the 59Th International Astronautical Congress (IAC), 29 September – 3 October, 2008, in Glasgow, Scotland.*

[17] Menrad, R. & Larson, W. (2008). Development of a NASA integrated technical workforce career development model entitled: Requisite occupation competencies and knowledge --the ROCK. In Presented at the 59th International Astronautical Congress (IAC), 29 September – 3 October, 2008, in Glasgow, Scotland.

[18] Squires, A., W. Larson, and B. Sauser. 2010. Mapping space-based systems engineering curriculum to government-industry vetted competencies for improved organizational performance. *Systems Engineering* 13 (3): 246-260.